Genetic and path coefficient analyses and heterotic orientation of maize germplasm under combined heat and drought stress in sub-tropical lowland environments

by

Pedro Silvestre Chaúque

BSc, Honors. Agronomy (Universidade Eduardo Mondlane, Maputo)
MPhil. Plant Breeding and Biotechnology (Moi University, Kenya)

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African Centre for Crop Improvement (ACCI)
School of Agricultural, Earth and Environmental Sciences
College of Agriculture, Engineering and Science
University of KwaZulu-Natal

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Thesis Summary

Crop failures due to simultaneous occurrence of drought spells and heat waves have become a common phenomenon in tropical and subtropical environments as a consequence of climate change. This phenomenon has raised lots of concerns among farmers and triggered serious debate among governments and scientists. There are no practical agronomic measures to control high temperatures in large open fields for crop production and investment in irrigation is unaffordable for the majority of the farmers in developing countries. Therefore, breeding for combined heat and drought stress tolerance is crucial in order to increase or stabilise maize productivity in tropical and sub-tropical regions. The present research was designed to, firstly, assess genetic variability for combined heat and drought stress tolerance in maize germplasm; secondly, investigate the level of relationship between maize traits correlated with grain yield in inbred lines per se versus hybrids under stressed and non-stressed conditions; thirdly, study gene action controlling maize grain yield and other agronomic traits under isolated heat, drought and combined heat and drought stress conditions; and finally, determine the heterotic orientation of thirty selected maize inbred lines towards three drought-tolerant and one high yield potential inbred tester lines.

A hundred and eight inbreds *per se* were evaluated under severe heat and drought stress, moderate heat-drought stress, random drought stress and non-stressed conditions to assess genetic variability for combined heat and drought stress tolerance. Results revealed existence of wide genetic variability for combined heat and drought stress tolerance among maize inbred lines available in Mozambique but superior genotypes under severe combination of heat-drought stress were not exactly the same under the rest of the growing conditions of this study. However, the study identified 15 out of 108 inbred lines (14%) as the most promising genotypes under severe heat and drought as well as under moderate heat and drought stress environments. The superior lines can be employed in the future breeding programmes for combined heat-drought stress tolerance.

Ten inbred lines, including two of the superior entries identified in the genetic variability study, were randomly assembled from the available maize germplasm in Mozambique and used to generate forty-five crosses in a half diallel mating design. The purpose was to study gene action controlling grain yield and other traits under combined heat and drought stress conditions. The diallel cross hybrids were evaluated together with three genetic testers under combined heat and drought stress, drought stress alone, heat stress alone and non-stressed

conditions. The yield reduction due to heat stress alone was 19% of the non-stressed experiment while reductions due to drought alone and the combined stresses were 41 and 59%, respectively, indicating that the combined stress condition was more detrimental than the individual stresses. For grain yield, additive gene action was predominant over non-additive and the magnitude of its predominance was larger under combined stress compared to individual stresses and non-stressed conditions. For the other traits, additive gene action was predominant regardless of the environment. The results imply that improvement of tropical maize for tolerance to combined heat and drought stress is possible and it can be faster when selections is conducted under combined stress conditions than either under heat or drought separately.

Thirty superior inbred lines (28 from the genetic variability study plus two other elite lines) were selected and crossed as female parents with four other lines as males in a line × tester mating design to assess heterotic orientation of the female parents towards the four male testers under stressed and non-stressed conditions. The resulting 120 testcrosses were evaluated under combined heat and drought stress and non-stressed conditions. Both general combining ability (GCA) due to lines and testers, and specific combining ability (SCA) due to line × tester mean squares were significant under the two water regimes of the study. The proportion of SCA effects was bigger than the total GCA effects under full-irrigation and equal under combined stress environment, indicating that SCA effects were more important than GCA effects under favourable conditions with the importance of GCA effects increasing under combined stress conditions. Combination of the new approach “heterotic group's specific and general combining ability” (HSGCA) and the traditional yield-SCA method successfully associated the thirty female lines to the four testers. It was found that heterotic orientation changed significantly with change in environmental conditions. Twenty inbred lines (67%) changed from one tester to another when experimental conditions changed from fully-irrigated to stressed conditions. Under full irrigation, tester N3 was related with 11 lines (37%) while under stressed condition only seven (23%) were found related with this tester. On the other hand, only five lines (17%) were assigned to tester CML444 under fully-irrigated condition but nine lines (30%) were assigned to it under stressed experimental condition. Testers CML312 and CML445 were related with seven lines (23%) under fully-irrigated condition and they only changed to more and less one line under stressed condition. The results suggest that appropriate tester must be identified and used for specific stress category.

Data from the line *per se* and diallel hybrid trials were used to investigate the level of relationship between grain yield (GY) and other traits under stressed and non-stressed

conditions. Genetic correlation coefficients were partitioned into direct and indirect effects following path coefficient analysis. In general, genetic correlation and path coefficients analyses revealed positive and significant relationship between GY and number of ears per plant (EPP) and ear aspect (EA) under stressed and non-stressed environments in both the inbred line *per se* and hybrid trials. This implies that EPP and EA can be used as indirect selection traits when breeding maize for both stressed (heat and drought) and non-stressed environmental conditions. The study also identified direct positive contribution of shorter anthesis-silking intervals (ASI) to GY under severe stresses but only indirectly through number of grains per ear (NGPE) under moderate stress environments. The NGPE had strong positive direct effect on GY while 100-grain weight contributed only indirectly through NGPE in hybrids. It can, therefore, be concluded from this study that EPP, EA, ASI and NGPE would be useful as secondary traits for maize GY selection under combined heat and drought stress conditions.

Declaration

I, Pedro Silvestre Chaúque, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. The thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   a) Their words have been re-written but the general information attributed to them has been referenced.
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Signed: _____ Date: 25/02/2017

Pedro Silvestre Chaúque (Candidate)

As the candidate's supervisors we agree to the submission of this thesis

_____ Date _____

Dr Julia Sibiya (Supervisor)

_____ Date: 13/3/2017

Prof. John Derera (Co-Supervisor)

_____ Date 13/3/2017

Dr Cosmos Magorokosho (Co-Supervisor)

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Dedication

To the heroes of my academic career:

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List of abbreviations

ACCI	African Centre for Crop Improvement
AD	Days to 50% anthesis
AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of variance
ASI	Anthesis-silking interval
CIMMYT	International Maize and Wheat Improvement Center
CML	CIMMYT Maize Line
CV(%)	Coefficient of variation given in percentage
DINA	Agriculture Directorate under the Ministry of Agriculture in Mozambique
EA	Ear aspect
EPO	Ear position = relative height of ear placement on the plant
F1	first generation of a cross between two genotypes
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistics
G X E	Genotype-by-environment interactions
GCA	General combining ability
IIAM	Acronym for Mozambican Agrarian Research Institute: Instituto de Investgação Agrária de Moçambique
IITA	International Institute of Tropical Agriculture
IL	Inbred line
INE	Acronym for the National Institute for Statistics in Mozambique: Instituto Nacional de Estatística.
INGC	Acronym for the National Institute for Natural Desasters Management: Instituto Nacional de Gestao de Calamidades
IRMA	Insect Resistant Maize for Africa
LP	Linha Pura, refers to released maize inbred lines at IIAM
LSD	Least significant difference
m.s.s.l.	Altitude measured in metres above sea level
MSV	Maize streak virus disease
MT	Metric tons
NGOs	Non-governmental organizations
OPV	Open-pollinated variety
PA	Plant aspect
PH	Plant height
QTL	Quantitative trait loci
RL	Root lodging
SADC	Southern African Development Community
SCA	Specific combining ability
SL	Stem lodging
SSgca	Sum of square due to general combining ability
SSsca	Sum of square due to specific combining ability
TCL	Testcross line
TIA	Acronym for the National agriculture surveys: Trabalho de Inquérito Agrário.

General Introduction

Importance of maize

Maize (*Zea mays* L.) is the major staple food crop in many African countries, especially in central and southern Africa. Setimela et al. (2007) and Langyintuo et al. (2010) estimate the contribution of maize to the diet of human beings in these regions to be about 70% of the total calories. Also, Tiba (2001) in the article entitled “Maize is life but rice is money” emphasized the importance of maize as a food crop in some African countries. A review by Harashima (2007) indicates that 95% of the maize grown in Africa is directly used for human consumption and it is predicted that, by 2020, the demand for this crop as food may be higher than that for rice and wheat.

Maize as a staple food is dominant throughout Southern Africa. Cutts and Hassan (2003) observed that although rice and wheat are also consumed, most of the supply is usually from imports while maize is generally a locally grown crop. These authors pointed out that maize is produced mainly for human consumption in the southern region of Africa with only about 5% used in animal consumption. According to this source, South Africa is the only exception where half of all maize is fed to animals. This scenario will continue for long since changes in eating habits are slow. In fact, maize requirements for SADC Region in 2015/16 was estimated at 34.50 million tonnes (Nyirenda, 2015) for an updated population of 277 million (http://www.southafrica.info/africa/sadc.htm#.Vmk51dJ97IU) in this region. *Per capita* consumption in the continental countries of the SADC Region is very high. Ranum et al. (2014) reported the highest estimate of 328 g person^{-1} day^{-1} in Lesotho and the lowest of 78 g person^{-1} day^{-1} in Botswana.

As in other African countries, maize is the primary food crop in Mozambique, with an estimated per capita consumption of about 57 kg year^{-1}, which is equivalent to an annual consumption of 315 kg per household (Tschirley and Abdula, 2007). According to this source, the maize share as food in the total household expenditure varies from place to place within the country, reaching to about 40% in the rural areas. Furthermore, a survey conducted across the country indicated that maize was the first choice food crop in seven out of the ten provinces of Mozambique, with 52.8% of the families considering it their primary food (MINAG, 2007). The

importance of maize grain in Mozambique also extends to animal feeding. Although statistics are not consistent and updated, some reports indicate large amounts of maize being imported from South Africa for the animal feed industry (MINAG, 2007) since the national production is insufficient to satisfy the demand for both human consumption and animal feed (SETSAN, 2010).

Maize is widely grown throughout Mozambique under diverse agro-ecological conditions and farming systems. It is found in 2,638,061 agricultural holdings (Table 0-1), corresponding to about 72% of the total holdings of 3,677,642 and it occupies more than 44% of the total area covered by the annual basic food crops (INE, 2011). Statistical data from FAOSTAT (2015) indicate that the annual grain production in million metric tonnes in Mozambique varied from approximately 2.2 in 2011 to 1.6 in 2013, with yields ranging from 0.7 to 1.2 t ha^{-1} between 2009 and 2013. The average yield for the five years is below all neighbouring countries except Zimbabwe (Figure 1), suggesting that there is huge potential to increase national maize production by improving yield levels. Maize yields vary from region to region and from environment to environment within a region in the country.

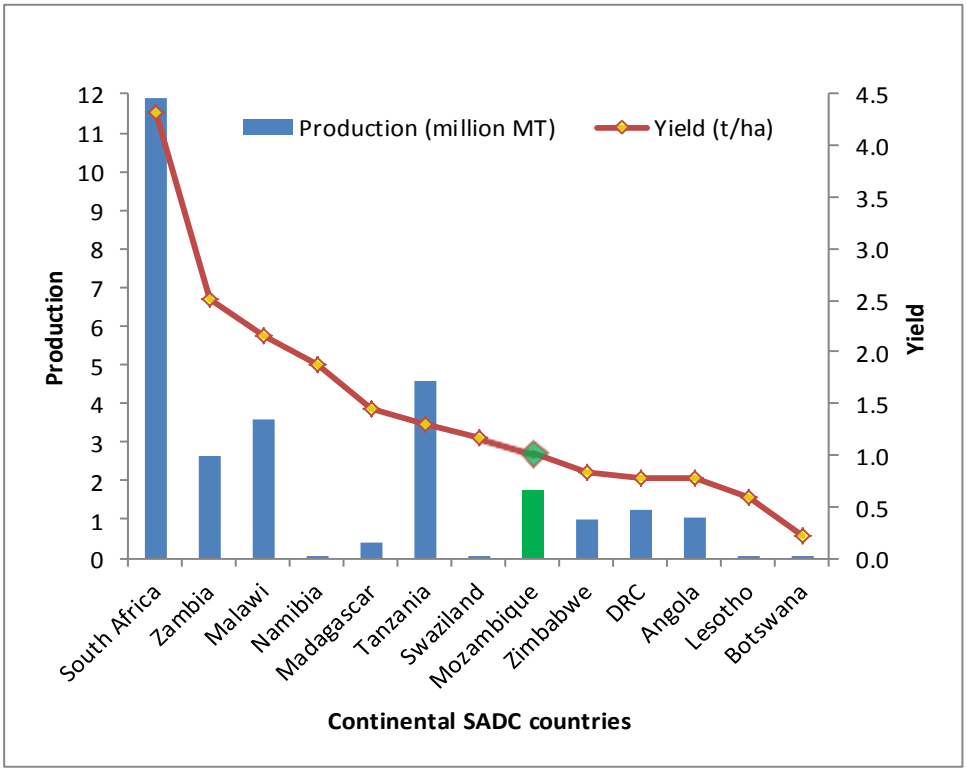

Figure 0-1. Maize production and yields in the continental SADC countries (2009 - 2013).

Source of data: (FAOSTAT, 2015)

The central and northern regions of Mozambique show much higher contributions to the national volumes of production compared to the southern region (Cunguara, 2012). Summarized data by Dias (2013) indicate that the north and central regions produce around 90% of the country's maize in about 82% of the total country maize area. This is because of better soil types and rainfall patterns in most of the agro-ecological regions in the north and centre compared to the south.

Table 0-1. Production of the annual food crops in Mozambique

Crops	Number of holdings (x 1000) [a]				Area cultivated (x 1000) [a]				Production[b]
	North	Centre	South	Total	North	Centre	South	Total	Average: 2009 - 2013
Maize	886	1 293	459	**2 638**	383	788	260	**1 431**	**1 738**
Cassava	1 082	932	411	**2 425**	483	368	187	**1 039**	**9 111**
Groundnuts, with shell	702	467	293	**1 462**	157	96	97	**350**	**114**
Sorghum	487	476	34	**998**	130	167	14	**311**	**322**
Cow peas, dry	588	623	458	**1 668**	116	109	136	**361**	**64**
Rice, paddy	169	342	28	**539**	72	188	22	**282**	**241**
Groundbeans	247	125	98	**470**	35	19	20	**74**	**-**
Pegeon peas	424	610	11	**1 044**	83	179	1	**263**	**-**
Beans, dry	71	202	15	**288**	38	55	6	**99**	**175**
Sweet potatoes	100	503	144	**747**	115	586	160	**861**	**894**
Millet	46	95	13	**155**	8	30	7	**45**	**49**
% of Total maize	**33.6**	**49.0**	**17.4**	**100.0**	**26.8**	**55.1**	**18.1**	**100.0**	

Source of data: a) INE (2011). Censo Agro-Pecuário (CAP) 2009/2010.
b) FAOSTAT (2015).

Maize production constraints in Mozambique

Maize production in Mozambique is dominated by small-scale farmers, accounting for 99% of the holdings (INE, 2011). As such, it is characterized by lack of credit to purchase agricultural inputs and agricultural equipment. Therefore, several constraints affect maize production and productivity in Mozambique. These constraints can be classified in three categories: socio-economic, biotic and abiotic factors. However the focus of this study is abiotic which includes drought, heat and their combined effects. These abiotic stresses are discussed in this chapter and the rest of the constraints are discussed in the literature review chapter. Drought has been long rated as the most important abiotic factor affecting crop productivity in Mozambique, especially that of maize (Bänziger et al., 2006; Setimela et al., 2007; SETSAN, 2010). As a concept, drought stress can be defined as "water deficit at any plant growth stage that results in

yield losses equal or superior to 10% compared to an adequately-watered control" (Reynolds et al., 2016).

Droughts are a historical phenomenon in Mozambique and are much more harmful than low soil fertility. An analysis of climatic changes (INGC, 2010) revealed that more than 16 million people in Mozambique were affected by droughts between 1965 and 2008; more than one hundred thousand died because of this natural disaster. Of all the natural disasters that occurred in the country during this period, 57% of the people have been affected by droughts (Table 0-2).

Table 0-2. Summary of impacts of natural disasters, 1965-2008, in Mozambique

Crops	People affected		People died	
	Number	%	Number	%
Droughts	886	22.6	100 200	95.2
Floods	1 082	27.6	1 921	1.8
Cyclones	702	17.9	697	0.7
Epidemics	487	12.4	2 446	2.3
Wind tempests	588	15.0	20	0.0
Earthquakes	169	4.3	4	0.0

Source: Adapted from INGC (2010)**.**

Even in years with good precipitation, its distribution during the cropping season varies from region to region across the country, leading to pockets of rainfall shortage and loss of maize production. In the north, rains are generally more reliable and less correlated to the rainfall patterns in the Southern Africa region (SA). Tschirley and Abdula (2007) highlighted that, even during the severest drought from 1992 to 1995 in the SA, both rainfall and maize production in the northern region of Mozambique were relatively unaffected. On the other hand, rainfall in the central region of the country is strongly correlated to that in SA and more variable than in north, but relatively reliable than in the south. Therefore, maize production fluctuations across the years in central Mozambique are comparable to those observed in the neighbouring countries (FEWSNET, 2011). In the south, maize productivity is the lowest, because the rainfall distribution is very poor, with much higher temperatures. Therefore, this region of the country depends on maize production from the central region, complemented by imports from South Africa, to meet its consumer demand.

Although Governmental and Non-Governmental Organizations have been advising farmers in the drought prone areas to grow drought-stress tolerant crops, such as cassava, sweet-potatoes

and sorghum, the majority of them insist on growing maize, because of their eating habits. Currently, it is difficult to recommend a maize planting date that will ensure crop development within the rainfall growing season even in the regions classified as high potential, due to unpredictable rainfall patterns. Irrigation would be an effective solution for the frequent losses of maize production. However, this option is practically unaffordable for the majority of farmers who dominate maize production in Mozambique. In fact, less than 2% of holdings interviewed during the Agrarian Census used irrigation, and mostly for rice, vegetables and sugar-cane (INE, 2003). Therefore, use of maize cultivars genetically improved for drought stress tolerance would be a better option for the majority of the farmers.

Breeding for drought tolerant (DT) maize has been top priority in the Mozambique Agriculture Research Institute (IIAM). Chaúque et al. (2004) reported some DT open-pollinated varieties that have been released. However, these are still not good enough to satisfy the farmers and the emerging national seed companies (Chaúque, 2009). Therefore, research addressing drought tolerance in Mozambique continues under the DTMA (Drought Tolerant Maize for Africa), WEMA (Water Efficient Maize for Africa) projects and local activities supported by the Alliance for Green Revolution in Africa (AGRA).

Unlike drought and low soil fertility, little has been mentioned about high temperatures as a production constraint in Mozambique. From the last five years, high temperature stress has been also recognised as having great negative impact on the maize yields (Harrison et al., 2011). Reynolds et al. (2016) defined heat stress as “supra-optimal temperatures occurring at any plant growth stage that can result in yield losses equal or superior to 10%”. In many parts of the world this factor has captured special attention from crop scientists due to its significant impact in reducing crop productivity in the tropical and subtropical environments (Ko et al., 2007; Lafitte and Edmeades, 1997; Long and Ort, 2010; Mittler, 2006; Wahid et al., 2007). Mitter (2006) emphasized that, in the USA, droughts combined with heat caused losses of about $US 4.2 billion between 1980 and 2004. In Mozambique as well, maize is not affected by drought only, but mostly by a combination of drought and high temperatures. Maize leaf firing as a result of high temperatures has been frequently observed during the period between November and March; however, this has never been documented. For example, maize leaf firing due to heat spells a few days after irrigation were observed in the WEMA-Mozambique yield trials grown under fully-irrigated and drought stressed regimes at Chókwè in November 2010 (Mugabe, 2012). Although the symptoms and effects on yield were more severe on the drought stressed

plots, the mean yield under full irrigation at the hotter site (Chókwè) was 2.0 t ha^{-1} less than the same experiment grown at Sussundenga (less hot) during the same season.

Solutions for heat stress in crops are difficult because there are no cultural practices to reduce sun irradiation in the field. Agronomic techniques, such as crop production under green or screen houses, are possible but unpractical when considering a crop like maize that is grown extensively on large acreages. As a consequence, failures of maize crop due to simultaneous occurrence of drought and heat stresses are frequently reported at the end of cropping seasons in Mozambique. The WEMA-Mozambique hybrid trials grown in 2010 at Chókwè Research Station provided evidence of genetic variation for heat stress tolerance and some genotypes exhibited fewer symptoms of leaf firing even under drought stressed conditions. Therefore, breeding for heat stress tolerance appears to be a strategy that can be used to minimize the impact of high temperatures in maize crop, especially a combination of both heat and drought stress tolerance in the same cultivars. However, no breeding activity for combined heat and drought tolerance has been initiated at present in Mozambique. Therefore, the aim of this research was to investigate the performance of different maize germplasm under combined heat and drought stress and identify the best performers.

Research Problem and Justification

Frequent failure of maize crops due to poor rainfall distribution and occurrence of heat stress during the main growing season in the tropical mid-altitude and lowlands of Mozambique is the main problem that drove the present research. The consequences of droughts in Mozambique have been clearly highlighted by the Institute for Management of Natural Disasters (INGC). In its publication entitled “Analysis of Climate Changes”, it reported that 16 444 000 people have been affected and 100 200 died between 1958 and 2008 as a direct consequence of drought (INGC, 2010). Maize in Mozambique is grown mostly during the warm season, running from mid-October to March in the south, from November to May in the centre and mid-December to June in the north. Therefore, apart from drought, high temperature effects also influence negatively maize crop productivity.

Harrison et al. (2011) analysed the impact of temperature changes on maize production in Mozambique and observed that extreme daily maximum temperatures were common from the end of September to March in the low and mid-altitude lands, between 1979/80 and 2008/09, producing significant changes to maize phenology and heat stress exposure. The study

concluded that temperature changes substantially threaten maize production in Mozambique. Therefore, breeding for combined heat and drought stress tolerance is crucial to increase or even to maintain maize grain yield in the future. For such a breeding programme to be successful, knowledge about different traits that are correlated with grain yield under combined heat-drought stress, and the kind of gene action governing the phenotypic expression of those traits under combined heat-drought stress, is required.

Objectives

Overall goal

To contribute for increased maize productivity in the tropical mid and lowland agro-ecological regions through development of suitable maize germplasm tolerant to combined heat-drought stress.

Specific objectives

1. to assess genetic variability for combined heat-drought stress tolerance in the available maize germplasm in Mozambique;
2. to study gene action controlling maize grain yield and other agronomic traits under isolated heat, drought and combined heat-drought stress conditions;
3. to determine the heterotic orientation of thirty selected maize inbred lines towards three drought-tolerant and one high yield potential males; and
4. to investigate the level of relationship between maize traits correlated with grain yield in inbred lines per se versus hybrids under stressed and non-stressed conditions.

Thesis outline

The above specific objectives were used to develop research chapters as follows:

Chapter 1: Literature review;

Chapter 2: Genetic variability for combined heat-drought stress tolerance in tropical maize germplasm;

Chapter 3: Gene action controlling maize grain yield and other agronomic traits under combined heat-drought stress conditions;

Chapter 4: Heterotic orientation of thirty maize inbred lines under fully-irrigated versus combined heat-drought stress conditions;

Chapter 5: Correlation and path coefficient analysis of maize grain yield with other characteristics under fully-irrigated versus water-limited conditions; and

Chapter 6: Overview of the research findings.

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1. Chapter 1. Literature Review

1.1 Introduction

This review discusses the main aspects on maize breeding for abiotic stress tolerance are discussed, with emphasis on drought and heat as follows: 1) major maize production constraints in Mozambique; 2) breeding approaches for maize heat and drought stress tolerance; 3) genetic control for heat and drought tolerances in maize; Morpho-physiological, biochemical and agronomic traits associated with maize grain yield under heat and drought stress conditions; 4) combining ability and gene action controlling quantitative traits of maize under non-stressed and combined heat and drought stress conditions; and 5) determination of heterotic orientation in maize.

1.2 Major maize production constraints in tropical lowland agro-ecologies

1.2.1 Socio-economic factors

The use of unimproved seeds with very low genetic potential for grain yield is a common socio-economic constraint in the majority of the farming systems (Langyintuo et al., 2010). This constraint cannot be solved directly by the breeding programme because it is caused mainly by a lack of education in association with a lack of credit to purchase agricultural inputs (Fato, 2010; Langyintuo et al., 2010; SETSAN, 2010). Because of the low education levels, many farmers fail to differentiate between grain and seed, and even between unimproved and improved varieties. Public extension services, seed companies and NGOs do operate in rural areas, delivering messages about use of improved technologies, but the level of adoption by farmers is still very low (Langyintuo et al., 2010).

1.2.2 Biotic factors

Field pests and foliar diseases are the main biotic constraints contributing to reduced maize yield in the tropic and sub-tropics (Segeren, 1994). The most important field pests are stem borers (*Chilo partellus, Busseola fusca* and *Sesamia calamistis*) (Cugala et al., 2003; Cugala et

al., 2009). *Busseola fusca* and *S. calamistis* are indigenous, while *C. partellus* is an introduced pest species in Mozambique. The abundance of each species varies from environment to environment. Cugala et al. (2003) reported predominance of *C. partellus* in the lowland warm environments, while in the mid-altitude areas both *C. partellus* and *B. fusca* were equally abundant. Similar distributions have been described by Segeren (1994), who added that *S. calamistis* was more important in the cool environments. Research focusing on insect (stem borers and storage insect pests) resistance is currently on going (Nhamucho, 2014).

In the case of foliar diseases, downy mildew (*Perenosclerospora sorghi*), maize streak virus (MSV), leaf blights (*Helminthosporium turcicum*), and grey leaf spot (*Cercospora zeae-maydis*) are of paramount importance in Mozambique (Denic et al., 2008; Fato, 2010). Breeding for disease resistance has been done for many years and satisfactory results were achieved. Moreover, projects addressing disease resistance are in progress under the Agricultural Productivity Programme for Southern Africa (APPSA) Project (Nhamucho, personal communication[1]).

1.2.3 Abiotic factors

Low soil fertility, especially low nitrogen, is one of the abiotic factors affecting maize productivity under small-scale farmers' fields in Mozambique. This constraint is mainly a result of declining soil nutrients content, the inaccessibility of fertilizers to the majority of the Mozambican maize growers (AFTS, 2006) and cultivation in sandy soils. Data from the Agrarian Census indicate that only about 3% of holdings used chemical fertilizers, but mostly for vegetables and very few for grain crops (INE, 2003). The National Maize Breeding Programme, in collaboration with CIMMYT, has been attempting to address the low soil fertility constraint since1995 (INIA, 2001). No substantial achievements have been reported as yet but other regional initiatives, such as the "Improved Maize for African Soils" - IMAS (www.cimmyt.org./en/improved-maize-for-african-soils) and "Sustainable Intensification of Maize and Legume System for Food Security in Eastern and Southern Africa" – SIMLESA (www.simlesa.cimmyt.org), are there to continue solving this constraint.

Other important abiotic factors are high temperatures and drought stresses. These have been recognised as the worst crop productivity stresses in many tropical and subtropical environments with huge economic losses in the agricultural sector (Chen et al., 2012). Stress in agriculture can be understood as a phenomenon through which the physiology, development

and function of plants are impaired resulting in irreversible damage to the plant system. When the stress is due to increased temperatures beyond the threshold level of a given plant species it is called heat stress. According to Wahid et al. (2007), heat stress is a function of intensity, duration and rate of the temperature increase. Similarly, drought stress is a status in which the plant system is deviated from its optimum equilibrium due to reduced soil water availability (Jaleel et al., 2009; Kotak et al., 2007). In maize, higher temperature stress is more dangerous when it occurs simultaneously with limited soil moisture because the typical C4 plant cooling system (Sage and Kubien, 2007) becomes deficient. In most of the tropical warm environments, a simultaneous occurrence of both high temperatures and soil water deficit is a common phenomenon. Therefore, the present chapter reviews the knowledge about different breeding approaches for abiotic stress tolerance and it assesses the important information on genetic control of heat and drought stresses in a maize crop, more precisely the gene actions governing tolerance to the two stresses. It also explores the knowledge about the genetic variability for heat and drought stress tolerance in tropical maize germplasm, and the use of heterotic groups for germplasm organization and management.

1.3 Breeding approaches for heat and drought stress tolerance in maize

Stress tolerance is the equilibrium between the need for yield production and survival (Burucs et al., 1994). In line with this concept, heat stress tolerance is the ability of the individual to produce more under environmental conditions characterised by temperatures above the optimum threshold range of the species and drought tolerance is the capacity to produce more economic yield under drought stress (Ribaut et al., 2009). Genetic improvement for abiotic stress tolerance in field crops can be achieved through selection for yield potential under optimum conditions (classical breeding) or through selection under target stress environment (Baum et al., 2007). The last approach is still subdivided in “empirical breeding” and “analytical breeding” (Araus et al., 2008; Baum et al., 2007). Various authors (Araus et al., 2008; Bänziger et al., 2006; Baum et al., 2007; Lopes et al., 2011) describe empirical breeding as an approach of direct selection for grain yield (GY) *per se* under stressed condition, while in the analytical (or Physiological) breeding there is indirect selection for secondary traits related to higher GY potential simultaneously in both stressful and optimum environments. Classical, empirical and part of physiological breeding approaches fall in a class popularly called conventional breeding. That is, selection of the targeted traits is carried out in segregating populations in which genetic variability is identified by visual observation. Nowadays, science has developed new tools to

allow identification of the genetic variation at the molecular level – molecular plant breeding (Araus et al., 2008; Bänziger and Araus, 2007a; Baum et al., 2007; Lopes et al., 2011; XU, 2010).

1.3.1 Classical approaches

It has been reported by various authors (Araus et al., 2008; Lopes et al., 2011; Reynolds and Trethowan, 2007) that breeding for grain yield potential under high yielding environment has resulted in tremendous advances in field crops. It has been also pointed out in some publications (Bänziger et al., 2000; Bolaños, 1995; Gill and Tilak, 2009) that earlier breeders believed that genotype exhibiting increased yield potential under optimum conditions will always show relatively better performance under stressed conditions. That belief has some legitimacy: Araus et al. (2008) and Cattiveli et al. (2008) observed that, when comparing genotypes exhibiting higher and lower yield potentials in a range of contrasting environments, crossover interactions are rare, suggesting that in general, genotype products of classical breeding approach show advantages over the lower yielding genotypes even under unfavourable environments; in maize, Tollenaar and Lee (2002) registered stress tolerance in hybrids bred for high yield potential. The advantage of classical breeding resides especially in the large genetic gains as a result of high heritability of GY under optimum conditions (Bänziger et al., 2000). Various authors (Araus et al., 2008; Burucs et al., 1994; Lopes et al., 2011) summarize the mechanisms exploited for drought stress tolerance in classical breeding in high root biomass and architecture (root depth and expansion), high shoot biomass, rapid overground coverage and high harvest index (HI). According to Bänziger et al. (2000), the high HI can be achieved by increased number of ears $plant^{-1}$, number of grains ear^{-1} and kernel weight. All this tolerance mechanisms imply increased demand in water (Tollenaar and Lee, 2006), making genotypes exhibiting these traits even vulnerable to drought stress susceptibility under severe drought stress.

When selecting specifically for abiotic stress tolerance, efficiency of classical conventional breeding approach decreases (Araus et al., 2008). It has been observed that higher yielding genotypes selected under optimum environmental conditions could significantly decrease their performance under moderate to severe stress growing conditions (Bänziger et al., 2006; Lopes et al., 2011; Maestri et al., 2002; Takeda and Matsuoka, 2008; Vaezi et al., 2010). This is because of the significant genotype-by-environment (GE) interactions and higher plot-to-plot

variation within environment leading to reduced heritability of GY and other quantitatively inherited traits under stressed conditions (Araus et al., 2008; Bänziger et al., 2006; Bolaños and Edmeades, 1996; Chimenti et al., 2006; Lopes et al., 2011). High yield potential may translate to increased demand in water and other resources. If high yield potential is not accompanied by an improvement in abiotic stress tolerance, genotypes that are products of classical breeding approaches will be vulnerable to stresses. Therefore, approaches that combine both empirical and physiological approaches, assisted by multi-environmental testing, would be more efficient.

1.3.2 Physiological approaches

Physiological breeding approaches have become model strategy for abiotic stress tolerance, especially drought and heat, in cereal crops. In wheat, Reynolds et al. (2001) reported important achievements of a collaborative work between CIMMYT and national programmes that date from 1990 incorporating physiological aspects of heat tolerance. In rice, Lafitte et al. (2004) reported application of physiological traits in improvement for low temperature and salt tolerance. Bavei et al. (2011) described several achievements of physiological breeding strategies for heat stress tolerance in spring barley. In general, selection for secondary traits correlated with GY under managed drought stress condition in open field environment is the most popular procedure used by many physiologist breeders.

In maize, many studies (Bänziger et al., 2002; Bolaños and Edmeades, 1996; Chen et al., 2010; Holá et al., 2010; Li et al., 2003; Shuja and Swati, 2011; Tollenaar and Lee, 2006) have been published highlighting importance of physiological approaches in breeding for drought tolerance. Bänziger et al. (2006) provided useful information on breeding for abiotic stress tolerance. The mechanisms of tolerance described in this publication include reduced production of absicic acid (ABA), increased osmotic adjustment through accumulation of solutes at the cellular level, proline accumulation, increased net photosynthetic activity (Pn), especially photosystem II, reduced anthesis-silking interval, reduced ear barrenness, and delayed leaf senescence (prolonged stay-green). Many other publications also have reported almost the same traits to be taken in account when breeding for abiotic stress tolerance in maize (Bänziger and Araus, 2007b; Betrán et al., 2003b; Betrán et al., 2003c; Bolaños and Edmeades, 1996; Holá et al., 2010; Shuja and Swati, 2011; Tollenaar and Lee, 2006).

For heat tolerance, relatively fewer publications on maize heat tolerance were found during this review compared to drought tolerance, and were only for understanding the physiological

mechanisms of heat stress tolerance (Chen et al., 2010; Cokun et al., 2009; Crafts-Brandner and Salvucci, 2002; Duke and Doehlert, 1996; Dupuis and Dumas, 1990; Jorgensen and Nguyen, 1995; Karim et al., 1999; Khodarahmpour et al., 2011; Kim et al., 2007; Mahmood et al., 2010; Sinsawat et al., 2004). In an in-vitro experiment, maize ovules fertilization was limited by temperatures higher than 36^{o}C and pollen was more sensitive to heat than the female tissues (Dupuis and Dumas, 1990). Duke and Doehlert (1996) observed reduction in kernel weight when grain filling period coincided with temperatures around 35^{o}C compared to grain filling period that occurred at temperatures around 25^{o}C. This suggests that growth of kernels at 35^{o}C ceased earlier than at 25^{o}C. Karim et al. (1999) tested the effect of heat stress in maize leaves of the same plants but with different ages. In that study it was found that developed leaves suffered more with heat than developing leaves. A study by Crafts-Brandner and Salvucci (2002) detected an inhibition of net photosynthesis (Pn) at leaf temperatures above 38^{o}C. The inhibition of Pn in this study was attributed to the decrease in activation of the Rubisco at temperatures greater than 32.5^{o}C. Similar scenario was observed by Sinsawat et al. (2004) when studying the effect of heat stress on the photosynthetic apparatus in maize. Kim et al. (2007) also investigated the temperature dependence of photosynthesis in maize and concluded that the optimum temperatures were around 34^{o}C. Another study on physiological response of maize to high temperature was conducted by Cokun et al. (2009). In this study there were relative leaf injuries of more than 60% when leaf temperatures exceeded 36.6^{o}C.

The physiological mechanisms responsible for both drought and heat stress tolerance have been subject of extensive studies in the main crop species. Increased water uptake, decreased transpiration rate, increased net photosynthesis, improved cell membrane stability, synthesis of heat-shock proteins (HSPs) and reduced production of reactive oxygen radicals (ROS) have been commonly pointed out as the most important physiological mechanism of abiotic stress tolerance, including drought and heat stresses (Araus et al., 2008; Dwyer et al., 2007; Efeoglu et al., 2009; Gill and Tilak, 2009; Hayano-Kanashiro et al., 2009; Maestri et al., 2002; Reynolds and Trethowan, 2007; Wahid et al., 2007). Selecting for most of these agronomic and physiological traits and determination of their relationship with GY under stressed conditions is a very complicated task due to the great spatial and temporal variability in the field evaluation of the stresses (Lopes et al., 2011). Therefore, molecular tools to assist on detecting the genetic variation and incorporation of the candidate target traits have raised high expectations in addressing the challenges imposed by the global warming to the major food crop species (XU, 2010).

1.3.3 Molecular approaches

Molecular breeding is a useful modern approach that allows identification of genetic variation of different traits at the molecular level (XU, 2010) and therefore, avoiding the complications due to year-to-year variability in the frequency, duration and intensity of abiotic stress within location (Lopes et al., 2011), specially heat and drought. Due to its initial cost (cost associated with laboratory establishment), the molecular breeding is justified in economically important crops and for economically important traits that are difficult to improve via conventional breeding (Araus et al., 2008). In concordance with this philosophy, the approach has been applied mostly in several major crops such as barley, cotton, common beans, maize, rice, soybeans, tobacco and wheat.

Characterization of molecular markers associated with drought tolerance has been done in quantitative trait loci (QTLs) mapping (Xoconostle-Cazares et al., 2011). Baum et al. (2007) provided an exhaustive review on the molecular breeding strategies for abiotic stress tolerance and actual achievements in terms of cultivars developed using this approach. Reviews on rice breeding for drought, heat and salt stress tolerance provide several examples of achievements through molecular approaches (Lafitte et al., 2004; Thomas and Howarth, 2000). In wheat, molecular breeding activities have been carried out on heat and drought stress tolerances (Al-Doss et al., 2011; Reynolds and Trethowan, 2007).

In maize, molecular approach has been used to assist in identifying QTLs that explain the genetic variability for most of the morpho-physiological traits highly correlated with GY under abiotic stress conditions, such as root architecture, ABA induction, duration stay-green, photosynthesis II, ASI, tassel size (Bolaños, 1995), production of HSPs (Feder and Hofmann, 1999), and cell membrane stability (Dwyer et al., 2007). However, many scientists agree that there is a long way from the molecular research findings and their practical applications (Phillips foreword in (XU, 2010), page xvii; (Araus et al., 2008; Bänziger and Araus, 2007b; Lopes et al., 2011) in the real agriculture due to differences in population sizes handled and the environmental conditions during the laboratory studies versus field crop production. Gill and Tilak (2009) highlighted that identification of markers for QTLs associated with drought tolerance has been difficult. Reynolds and Trethowan (2007) also emphasized that the chance to allocate all genes associated with a complex trait decreases with the number of loci and their magnitude of effect.

1.4 Genetic control of heat and drought tolerances in maize

Abiotic stress tolerance is a result of many biochemical and physiological mechanisms, all genetically controlled (Moreno et al., 2005). This makes breeding for abiotic stress tolerance even more difficult, therefore the use of indirect measures becomes important (Reynolds and Trethowan, 2007). However, because a cultivar with high stress tolerance has no value if it cannot produce economic yield (Bänziger et al., 2000), GY must be the primary trait to be considered even when the target of the breeding programme is abiotic stress prone environments. In conventional breeding, these measures imply careful identification of the morphological and physiological traits associated with GY, commonly denominated as secondary traits (Araus et al., 2008; Bänziger et al., 2000), and their related biochemical pathways (Lopes et al., 2011).

As mentioned before, everything that happens in a living organism is genetically controlled. According to Falconer and Mackay (1996), the genetic control of a trait include the mode of inheritance (monogenic or oligogenic versus polygenic inheritance) and the gene action that leads to the expression of the trait. Understanding the genetic control of the most important traits that contribute significantly to improved heat and drought stress tolerance is important to help designing appropriate breeding strategies. As a starting point, the question whether there is enough genetic variation for the traits of interest within the crop species must be answered.

1.4.1 Genetic variability for heat and drought stress tolerance

Heat and drought stress are usually associated since transpiration which cools the plant is reduced when leaves roll (Bita and Gerats, 2013). Warmer temperatures increase development rate more than photosynthetic rate, so less assimilates would be available per growth stage, resulting in reduced yields (Edmeades, 2013). As a consequence, yields decline, but crops will mature more rapidly. The yield reduction under hot conditions is also due to the negative effects on the mechanisms that influence crop yields when the plant tissue temperature increases above the crop threshold. According to Naveed et al. (2014), maize plant growth is negatively affected at temperatures above 32^{o}C and crop yields can be reduced by more than 100 kg ha^{-1} every day when temperatures exceed 35^{o}C during anthesis and grain filling periods. Sánchez et al. (2014) reviewed many literature resources and concluded that the key threshold temperature for maize is between 32 - 37^{o}C. It has been also reported that a combination of heat and drought stresses is more detrimental than when each of the stress occurs individually (Cairns et

al., 2013a; Cairns et al., 2013b; Kebede et al., 2012; Mittler, 2006; Vile et al., 2011; Wahid et al., 2007). Analysing a data set of more than 20,000 maize trials in Africa, (Lobell et al., 2011) found that maize yields were reduced by 1% per each degrees day above 30^{o}C under optimum conditions and by 1.7% under drought stress conditions. This study showed that the upper limit of optimum temperature is not that high even for tropical maize germplasm.

Therefore, identification of maize genotypes that can agronomically withstand the combined effects of heat and drought stress would be a better solution to mitigate the impact of the climate changes that are expected worldwide. Replacing existing cultivars with later maturing introductions would partially offset the duration of vegetative period with yield but it would contradict the important option of drought escape. Therefore, other traits must be considered when selecting for combined heat and drought stress tolerance. Identification of heritable genetic variation is the first requirement for genetic progress in breeding for stress tolerance (Blum, 2011).

Existence of large genetic variability is a pre-requisite for success in a breeding programme for any trait in order to optimize response to selection. Although landraces may carry unique alleles, their breeding value for grain yield is usually very low (Edmeades, 2013) due to high dose of recessive deleterious alleles. The feasible option is to search for genetic variability in adapted and elite germplasm (Blum, 2011). Maize improvement for drought tolerance has received special attention from many breeding programmes in countries located in tropical and subtropical climates (Adebayo et al., 2014; Agrama and Moussa, 1996; Badu-Apraku et al., 2012; Bänziger et al., 2000; Betrán et al., 2003b; Campos et al., 2004; Chimenti et al., 2006; Derera et al., 2008; Edmeades et al., 1997; Edmeades et al., 1998; Edmeades et al., 2001; Hayano-Kanashiro et al., 2009; Khalili et al., 2013; Khayatnezhad et al., 2011; Makumbi, 2005; Oyekunle et al., 2015; Ribaut and Ragot, 2007; Shiri et al., 2010; Tollenaar and Lee, 2006; Zhang et al., 1999) but there is very little on heat tolerance up to date.

In the case of heat, Bai (2003) observed significant variation for all heat tolerance related traits among 179 recombinant maize inbred lines developed from a cross between a heat tolerant and heat susceptible inbred lines. In another study by Khodarahmpour et al. (2011), variations among inbred lines as well as among hybrids for heat stress tolerance were detected and the best lines and hybrid combinations for heat tolerance were identified. On the other hand, Lu et al. (2011) screened 550 inbred lines for drought tolerance in Tlaltizapan-Mexico, a tropical environment, under well-watered and water-stressed conditions, with average maximum

temperature during the growing experiment of 33^{o}C, identified inbred lines that showed strong drought tolerance. These results indicated that some drought tolerant inbred lines also carried important genes that helped the plants withstand the environmental conditions that were characterized by a combination of drought and heat stress. In another study by Cairns et al. (2013) it was found that not all drought tolerant lines were heat tolerant. Furthermore, the study revealed that many of the elite drought tolerant donors widely used in Africa were susceptible to drought stress at elevated temperatures. In conclusion, it was stated that genetic tolerance to combined heat and drought stress in maize was distinct from tolerance to individual stresses and that tolerance to heat or drought separately did not imply tolerance to combined stress.

1.4.2 Inheritance of grain yield and other important traits

Grain yield is a complex polygenic "super-character" that is a product of the plant density and "sub-characters", namely number of ears plant^{-1}, number of grains ear^{-1} and average grain weight as described by (Moreno-Gonzalez et al., 1993). These "sub-characters" or yield components must be handled together in a breeding program to achieve a satisfactory level of grain yield under certain environmental conditions. Grain yield reduction under both heat and drought stresses have been reported in various studies (Bänziger and Araus, 2007b; Derera et al., 2008; Hussain, 2009; Jumbo and Carena, 2008; Kaur et al., 2010; Setimela et al., 2007; Vivek et al., 2009b) and genotypic differences have been observed.

In conventional breeding approaches, the common way to assess the inheritance of the traits is to investigate the type of gene action involved in the genetic component of the total phenotypic expression of each trait (Hallauer, 2007b). According to Falconer and Mackay (1996), there are two types of gene action: additive and non-additive gene action. In many crops and for most of the traits, the predominance of either additive or non-additive gene actions is usually dependent to the population in study and it cannot be generalized (Hallauer, 2007b). One procedure popularly used to investigate the gene action is to assess the combining ability for a particular trait. Fehr (1939) defined combining ability as the potential of a line to produce a superior combination with others for a given character. The author categorized combining ability in general (GCA), the average performance of a line in crosses with other parents, and specific (SCA), the performance of a line in a cross with a specific parent.

Since this concept was developed, breeders have adopted it in their breeding programs in order to identify the mode of inheritance, and then, suggest appropriate breeding strategies for a

particular trait in different crops, or to select desirable parents for future hybrid production in the case of cross-pollinated crops. Studies have been done in combining ability for grain yield, yield components and yield associated traits under diverse environment conditions. Although most of the findings gave evidence of significant effect of both GCA and SCA for grain yield and related traits (Derera et al., 2008; González et al., 1997; Hallauer, 2007b; Hallauer et al., 2010; Sprague and Tatum, 1942), suggesting importance of both additive and non-additive genetic control, it has been also clear that the predominance of each depends on the crop and materials within the same crop species.

Gamble (1962a) hypothesized that when the material used to obtain the genetic variance estimates become more restricted or more selected in genetic background, the additive variance for grain yield in maize may be reduced, giving more predominance of non-additive gene effect. This author reported only minor contribution of additive effects for inheritance of grain yield in the studied group of maize inbred lines. It was found that all significant estimates of additive effects were positive, however, this changed when the position of the parent changed (reciprocal crosses). Another important conclusion that Gamble (1962a) made is that epistatic effects were important for grain yield, especially the additive × additive and additive × dominance interactions, but only few crosses exhibited dominance × dominance or the three types of epistasis simultaneously.

In their search for epistasis, Moreno-Gonzalez and Dudley (1981) and Sofi et al. (2006) concluded that the two types of genetic variation were important, but non-additive variation contributed more than the additive one, suggesting more predominance of dominance and epistatic interactions in controlling grain yield and related traits. Equally, Sprague and Tantum (1942) compared the importance of GCA versus SCA in single crosses of maize and they found evidence of large predominance of GCA, although SCA was also statistically significant. Working with barley (*Hordeum Vulgare*), Sharma et al. (2002) also found GCA/SCA ratio smaller than a unit, indicating that the genotypic variation was more attributed to specific than to general combining ability.

There are many researchers whose findings are contradictory to the above. Ojo et al. (2007) and Egesel et al. (2003) in maize, Nazir et al. (2005) in wheat (*Triticum aestevum*), Thomas and Sreekumar (2001) in black gram (*Vigna mungo*), Panhwar et al. (2008) in cotton (*Gossypium hirsutum*), Kimani and Derera (2008) in dry beans (*Phaseolus vulgaris*), and Kenga et al. (2006) in sorghum (*Sorghum bicolor*), are some examples of authors who reported relatively high

predominance of additive than non-additive genetic variations for grain yield in different crop species.

Traits that are not yield components have mostly been found to be controlled primarily by additive gene action in various crop species, although in many cases non-additive gene effects have also been found playing important role. Wegary et al. (2014) reported predominance of GCA over SCA effects for most maize agronomic traits tested under drought, low-nitrogen and optimum environmental conditions. Kimani and Derera (2008) observed significant effects due to both GCA and SCA in dry beans for all traits, and concluded that additive gene action was more important than non-additive. Working with common beans, Derera et al. (2008) found 66% of the genotypic variance due to GCA, indicating the predominance of additive over the non-additive gene action in conferring resistance to anthracnose (*Colletotrichum lindemuthianum*). Similar results were reported in maize by Jung et al. (1994).

As quantitative characters, grain yield and yield component traits, are greatly influenced by the environment. Sun light, temperature, water availability and soil fertility are the most important environment factors affecting the genetic expression for grain yield (Bänziger et al., 2000). Several studies have demonstrated that both GCA and SCA for grain yield in maize are influenced by environment (Derera et al., 2008; Egesel et al., 2003; Ojo et al., 2007) indicating that the performance of the lines themselves and their behaviour in different combinations may differ according to the conditions in which the hybrids are grown. In quality protein maize (QPM), Bhatnagar et al. (2004) did not find significant effects of GCA for grain yield, but its interaction with environment was significant. On the other hand, the same author found significant effect of SCA, yet, its interaction with environment was not significant. In a dialell analysis of nine quality protein maize inbred lines evaluated under optimum conditions, Machida et al. (2010) observed that SCA effects were dominant over GCA effects for grain yield. Testing 15 quality protein maize inbred lines under drought and low-nitrogen stresses and optimal conditions, Wegary et al. (2014) reported that GCA and SCA mean squares were significant for all measured traits including grain yield, indicating that additive and non-additive genetic effects were important in the set of germplasm under all test environments. In the study by Wegary et al. (2014), the GCA effects were more important under drought stress, while SCA effects were more important under low-nitrogen and optimal conditions for grain yield.

Root properties

Root characteristics, especially root depth, is one of the traits considered correlated with grain yield under both heat and drought stress (Ribaut et al., 2009). The correlation between root depth and heat tolerance is explained by the ability of the plant with deeper roots to capture water for transpiration (leaf cooling system) from depths that cannot be achieved by susceptible genotypes.

Vacaro et al. (2002) investigated combining ability of 12 maize populations in a diallel mating design for different traits including root system. This study revealed also a predominance of additive gene action for root depth as the GCA variance was larger than the SCA variance. In another study, Chun et al. (2005) investigated specifically the genetics of the maize root characteristics in response to low nitrogen stress. This study did not find changes in root biomass, but in root depth. Both GCA and SCA variances were equally significant indicating the importance of both additive and non-additive gene actions in controlling the root depth.

In a PhD thesis, Hussein (2009) conducted studies related to genetics of drought tolerance in maize, where he looked at many traits related with GY, including root aspects, under both stressed and non-stressed conditions. Hussein reported significant genotypic variation in root properties and he observed that genotypes with high root length and fresh root weight coincided with genotypes tolerant to drought. Recently, Oliveira et al. (2011) published results obtained in a 6 x 6 half diallel study in which they also found significant variation in root depth but no changes in total root biomass were observed. Significant GCA and GCA × production system interaction effects were detected in the analysis, but SCA was only significant for GY and plant height. Based on these results, the authors concluded that the most important root property is the depth and that it is controlled by additive gene action with different magnitude depending on the soil characteristics. Analysing data from a 6 × 6 maize diallel experiment grown under normal and high temperature conditions, Akbar (2008) found importance of both additive and non-additive gene effects under both environments. However, under heat stress the additive genetic variation reduced significantly. This increased the relative proportion of non-additive variance for root biomass, with greater predominance of maternal effect.

Plant height and ear position

Plant height and ear position (ratio between the plant height and ear insertion height) are important for heat and drought tolerance because of the very large distance between the ear insertion and the tassel of maize (Bänziger et al., 2000). This makes the pollen to be more

susceptible to heat and desiccation (Betrán et al., 2003c), therefore, tolerant genotypes tend to have shorter plant phenotypes (Ribaut et al., 2009). Recent study by Aly et al. (2011), revealed significant additive gene action compared to non-additive action in controlling plant height of testcross hybrids evaluated under normal growing conditions. Surprisingly, Bello and Olaoye (2010) did not detect significance of neither GCA nor SCA variances in a two years experiment with 10 open-pollinated varieties conducted in a typical southern guinea savannah ecology of Nigeria. Although some studies have indicated large proportion of SCA than GCA effects (Akbar, 2008), other studies in maize were consistent in attributing importance of additive effects in controlling plant height (Malacarne and San Vicente, 2003).

Sibiya (2009) analysed data from different environments of maize half diallel crosses generated from 10 parents and found significant effect of GCA but not SCA, for plant height and ear position, suggesting importance of only additive gene action under the conditions of that experiment and for the germplasm under consideration. Results from Teklewold and Becker (2005) show even more than 8 times larger GCA than SCA sum of squares in Ethiopian mustard, but Sharma et al. (2002) in barley and Passos et al. (2010) in *Ricinus communis* reported larger SCA effect than GCA. Under drought stress conditions Hussain (2009) reported significant additive and dominance genetic variances, with no maternal effect, for plant height. Additive gene effects were predominant over dominance gene effects.

Under stressed conditions, Jumbo and Carena (2008) concluded that only additive gene action was important for ear position (ratio between plant height and ear height), since only GCA effects were significant in a half diallel analysis involving seven parents. Specific combining ability and genotype-by-environment interaction effects were not significant at all. Very similar results were reported by Mhike et al. (2011) in a study of 100 hybrids generated by 10 × 10 North Carolina design II. The experiment was conducted in both stressed and non-stressed conditions and only GCA effects were significant for plant height and ear position, again with no interaction effect between genotypes and environments.

Leaf area and leaf rolling

Leaf area and leaf rolling are important maize traits to be considered when screening for heat and drought tolerance. Large leaf area results in high amount of sun light capture, therefore high photosynthetic rate (Reynolds and Trethowan, 2007). However, Banziger et al. (2000) called attention to the fact that large leaf area increases transpiration rate, thus, increasing stress

vulnerability. Various studies demonstrated genetic variability for maize leaf rolling under drought stress conditions (Moulia, 2000), but little was found published on this trait under heat stress in maize. Under drought, Zaidi et al. (2008) observed consistent significant and negative correlation between maize leaf rolling and grain yield, suggesting that selection must be directed to unrolled leaves under drought. Similar findings were reported in Chen (2010)'s studies on genetics of characters associated with drought tolerance in maize.

Additive gene action controlling maize leaf rolling was reported by Durães et al. (2011) as one of the traits evaluated under drought stress condition in EMBRAPA-Brazil. The study by Husasain (2009) also identified additive gene action as the most important in controlling the rate of leaf rolling. Under heat stress and cooler environments, Akbar (2008) reported importance of both additive and non-additive gene action, with predominance of additive type.

1.5 Morpho-physiological, biochemical and agronomic traits correlated with maize grain yield under heat and drought stress conditions

Genetic improvement for abiotic stress tolerance can be achieved through direct selection for grain yield (GY) in a target environment (empirically) or analytically (physiological breeding) by an indirect selection for secondary traits related to higher GY potential simultaneously in both stressful and optimum environments (Araus et al., 2008). In general, selection for secondary traits correlated with GY under managed drought stress conditions in open field environments is the most popular procedure used or advocated by many plant physiologists and breeders (Araus and Sanchez, 2012; Bavei et al., 2011; Kebede et al., 2012; Liu et al., 2011; Lopes et al., 2011; Mhike et al., 2012; Molina-Bravo et al., 2011; Obeng-Bio et al., 2011; Reynolds and Trethowan, 2007; Sinclair, 2011; Takele, 2010; Talebi, 2011; Tollenaar and Lee, 2006; Vaezi et al., 2010; Wahid et al., 2007; Weber et al., 2012; Zhuan-Fang et al., 2011). However, it has been well demonstrated in most of the above publications that for a secondary trait to be useful in selection for stress tolerance it must fulfil certain attributes. More specifically, Bänziger et al. (2000) in maize, Fischer et al. (2003) in rice and Reynolds et al. (2001) in wheat gave exhaustive recommendations for the use of secondary traits in breeding for drought, low soil fertility and heat stress tolerance in those crops. These authors agree that the following attributes must be observed for a secondary trait to be useful. First, it must be genetically correlated with GY in the stress under consideration. It is also important that the trait be less affected by environment (less genotype-by-environment interaction) than GY. Therefore, a

useful secondary trait must exhibit greater heritability than GY itself. It must be faster, easier and not expensive to measure than assessing GY itself. It must be easily assessed in individual plants or in very small plots.

In Bänziger et al. (2000), the number of ears per plant, anthesis-silking interval, leaf rolling, leaf senescence and tassel size were described as the most helpful secondary traits to identify drought tolerance in maize, while for low nitrogen stress tolerance the same traits were considered important but not leaf rolling and tassel size. Very recently, Mhike et al. (2012) validated the use of secondary traits and selection indices for drought tolerance in tropical maize. He concluded that anthesis-silking interval and number of ears per plant were the most useful secondary traits because they were consistently and strongly correlated with GY. Although some common plant traits are observed under both drought and heat stresses, it has been emphasized that drought tolerance does not necessarily indicate heat tolerance (Prasad et al., 2008). This is because the molecular and biochemical responses of plants to a combination of the two stresses are unique and cannot be extrapolated simply from responses to the individual stresses (Mittler, 2006). Bai (2003) studied GY under heat stress and its correlation with other physiological and agronomic traits in maize. It was found that yield per plant was negatively correlated with percentage of leaf firing and days to flowering and positively correlated with chlorophyll fluorescence and number of tassel branches. Also, Akbar (2008) investigated the significance of the correlation coefficients among the different traits whilst studying the genetic control of high temperature tolerance in maize. Cell membrane thermo-stability, stomata conductance, transpiration rate, leaf water potential, leaf osmotic potential, turgor potential, growing degree days to flowering, growing degree days to maturity and growing degree days between tasseling and silking were the physiological traits whose correlations with grain yield per plant were analysed. In terms of agronomic traits, plant height, ear leaf area, number of grains per plant and 100 grain weight were included. All agronomic traits were found to be significantly correlated with grain yield per plant under both normal and high temperature conditions, except 100 grain weight under optimum conditions. Interestingly, no genetic correlation was observed between morphological traits and grain yield per plant under normal temperature, with the only exception of the growing degree days between tasseling and silking. In contrast, under high temperature stress, most of the physiological traits were genetically correlated with grain yield per plant, apart of leaf water potential, stomata conductance and growing degree days to flowering and maturity. Thus, the relationship among plant traits changes according to the type of stress under consideration. Hence, it will be helpful to

investigate whether under combined stresses the traits correlated with grain yield will be the same as the sum of the traits under drought and under heat stresses separately.

1.6 Genetic control of maize quantitative traits under unstressed and combined heat and drought stress conditions

Quantitative genetic studies were more extensively conducted with maize compared to other crop species, and most of the estimates for genetic components of variance showed a preponderance of additive variance (Hallauer et al., 2010). Additive and dominance gene actions account for more than 90% of the total genetic variance for most of the quantitative traits in several studies (Hallauer, 2007a), while estimates of epistatic variances were in most cases large and negative. However, Hallauer (20017a) advises that epistasis may be as important as additivity and pure dominance when studying genetic control of quantitative traits, because of the large number of genes that are normally involved in the expression of those traits. Bauman (1959) attempted to find evidence of non-allelic gene interaction in determining GY, ear length and number of kernel rows in maize. Although epistatic effects were found to be significant in that study, some epistasis × year interactions were also significant. Thus, Bauman highlighted that the epistatic effects in some cases may be confounded with genotype-environment interactions. Also Gamble (1962b; a) studied genetic effects in some maize traits including GY and reported interesting results related to epistasis: it was observed that epistatic gene effects were relatively more important than additive gene effects but less than dominance gene effects for the material studied. However, only additive gene effects were consistent over environments followed by additive × dominance epistatic effects.

Twenty years later, Moreno-Gonzalez and Dudley (1981) compared different methods of measuring the importance of epistasis in maize. Epistatic effects were found significant but small compared to additive and dominance variation in several crosses for many characters, except for GY where only the dominance effects were significant when tested against the appropriate interaction mean squares. In another study involving early flint and dent inbred lines, all types of gene action were significant but dominance effects were greater than additive and epistatic effects for grain yield and plant height (Melchinger et al., 1986). Similar findings were reported in many of the recent studies under unstressed environments (Aly et al., 2011; Bello and Olaoye, 2009; Iqbal et al., 2010b; Iqbal et al., 2010a; Kumar et al., 2012; Oliveira et al., 2011).

Under drought stress growing conditions, Fu et al. (2008) revealed that dominance was more important than additive effect for plant height, anthesis-silking interval, root weight and grain yield per plant, whereas both additive and dominance effects were almost equally important for the leaf emergence rate. Fu et al. (2008) observed that the variances for specific combining abilities were about double the variances of general combining abilities for plant height, anthesis-silking interval and grain yield per plant, but they were about equal for leaf emergence rate and root weight. This was a clear indication of a preponderance of dominance gene action compared to additive. Contrarily, Betrán et al. (2003b) found additive gene action to increase with the intensity of the drought stress in tropical maize inbred lines. Using 27 Southern African maize inbred lines in sets of NCDII mating designs, Derera et al. (2008) investigated gene action controlling grain yield and secondary traits under drought stress and non-stressed conditions. In general, their findings indicate predominance of additive action in governing the phenotypic expression of most of the traits, especially GY, under both stressed and non-stressed conditions, but the importance of non-additive gene action appeared to be bigger under non-stressed environments. This suggests that, regardless of the type of germplasm, gene action seems to change depending upon the intensity of drought stress. Similar findings have repeatedly been reported in recent studies on drought tolerance in maize (Hussain et al., 2009; Makumbi et al., 2011; Meseka et al., 2011; Mhike et al., 2011).

Although the negative impact of heat stress on maize productivity in tropical environments has been recognized for quite a long time, there are relatively few studies on genetic control of heat stress tolerance in maize compared to drought stress tolerance. This is probably due to the complexity of heat stress assessment under field conditions. The earliest publication on genetic effects of heat tolerance in maize was by Jorgensen and Nguyen (1995). They analysed the genetics of heat shock proteins (HSPs) in maize, which were reported to be correlated with heat tolerance in many species including maize (Hu et al., 2010; Jorgensen et al., 1992). The study revealed a single gene inheritance characterized by three types of intra-allelic interaction (complete dominance, over-dominance and co-dominance) determining the synthesis of HSPs under heat stress treatment. Later, Tassawara et al. (2007) studied gene action and combining abilities for thermo-tolerance in maize. Five heat tolerant and five heat susceptible lines were crossed with four heat susceptible testers in a line × tester mating design. The progeny were evaluated in a season with maximum temperatures reaching up to 40^{o}C. The dominance type of gene action was predominant for all the 13 traits recorded in that study. Another genetic study of heat tolerance in maize was conducted by Kaur et al. (2010). Combining ability for heat stress

tolerance in spring maize was investigated using a 12 × 12 diallel mating design under heat stress (maximum temperatures ranging from 35 to 45^{o}C during the flowering time). Both additive and non-additive gene action were found to be involved in the inheritance of all the studied heat tolerance and yield contributing traits, but only leaf firing was significantly correlated with GY. Leaf firing was also strongly correlated with tassel blast, indicating that the two traits are useful when selecting for genotypes adapted to hot environments.

All the current knowledge about the inheritance of grain yield and other important traits suggests that the predominance of a type of gene action is dependent on the type and number of genotypes involved, and also on the type and intensity of the stress under which the traits are assessed. Now, the question is: what are the gene actions controlling characters related to maize GY under combined heat and drought stress condition in tropical germplasm? The answer for this question requires research under conditions characterized by a combination of the two stresses. For comparison purposes, the same germplasm also need to be tested also under non-stressed, isolated heat stress and isolated drought stress conditions.

1.7 Determination of heterotic orientation in maize

To facilitate a systematic exploitation of heterosis, it is necessary to use heterotic groups and identify heterotic patterns among the available maize germplasm. This is so because of the weak correlation between the performance of the inbred lines *per se* and their hybrid progenies for most of the agronomic characters, especially grain yield (Hallauer, 2007a).

According to Melchinger and Gumber (1998), heterotic group can be defined as a group of genotypes, from the same or different populations, which display similar combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm group. On the other hand, heterotic patterns are crosses between known genotypes that express a high level of heterosis (Carena, 2008). Accordingly, the heterotic effects will be unique for each hybrid, because the specific combinations of dominance and epistatic effects are different for each hybrid.

Different breeding programs, in different countries, regions or institutions, have different systems to classify their breeding materials in to heterotic groups. However, the International Maize and Wheat Improvement Centre (CIMMYT) divide its maize germplasm in to basically two heterotic groups, A and B (Vasal et al., 1999). Heterotic group A (HGA) includes N3, Tuxpenõ,

Kitale and Rid types, while heterotic group B (HGB) it is comprised of SC, Eto, Blanco Ecuador, and Lancaster types.

Depending on the source materials and ultimate goal, breeders choose different methods to classify maize germplasm in to different heterotic groups. One of methods consists of separating inbred lines based on their specific combining abilities (SCA) from a diallel analysis with the respective line-pedigree information (Malacarne and Vicente, 2003). With this method, the best heterotic pattern for grain yield provides the discriminating parents. A line is assigned to the same group with a given discriminator if their estimated SCA is negative. Using the diallel cross approach, Gonzalez et al. (1997) classified ten maize inbred lines into HGA and HGB by comparing the sign of their SCA effects. Lines with positive SCA with a discriminator were assigned to one heterotic group, while those with negative signal were assigned to the other group. However, Zhang et al. (2002) observed that the reliability of SCA from diallel analysis depends upon the quantity and genetic basis of the inbred lines used as parents, therefore, it restrict its application for heterotic group classification. This was also supported by Fan et al. (2009) who highlighted that different studies might assign the same inbred line to different heterotic groups, because SCA effects are greatly influenced by the interaction between two inbred lines and by hybrid-by-environment interaction.

Another method employs heterotically contrasting and known testers, in a factorial line-by-tester mating design, to discriminate new inbred lines, also based on the SCA signal. Many maize breeding programmes use this method because it accommodates the large numbers of new inbred lines that are commonly handled in their programmes. Malacarne and Vicente (2003) used two heterotically divergent tester lines, to classify 42 new inbred lines, with different endosperm hardness, in two heterotic groups. One important conclusion from their study was that the endosperm type does not necessarily allow predicting heterosis or heterotic patterns, especially when the lines were extracted from a broad genetic base source population. Their results showed that most of the dent-type lines belonged to HGA, while HGB included both dent and flint-type lines. To classify CIMMYT elite early maturing maize lines, Mawere (2007) also followed the line-by-tester approach, but using single-cross hybrids (A × A and B × B) as testers. Five out of the sixteen inbred lines were assigned to HGA and other five to HGB. Three lines combined well with both the testers; therefore, they were classified as AB group. The remaining three lines showed poor performance, with either tester A or B, so it was impossible to classify them with this method.

With the discovery of molecular markers, genetic similarity or genetic distances are used to heterotically separate maize germplasm. Molecular marker technologies can detect DNA polymorphism at any stage of plant development and are not influenced by environment. Menkir et al. (2004) classified thirty-eight maize inbred lines using their SCA with two tester lines representing two divergent heterotic groups, and using their genetic similarity assessed by AFLP and SSR molecular markers. These molecular markers assigned the inbred lines to heterotic groups different from those assigned by SCA with the known testers. The authors concluded that molecular marker-based grouping might only serve as a basis for designing and carrying out combining ability studies in the field to establish clearly defined heterotic groups. Barata and Carena (2006) also evaluated the consistence of SSR (49 primers) and testcross grouping of thirteen maize inbred lines. Their results showed that heterotic groups of genetically similar germplasm could not be identified accurately and reliably with molecular markers even when the tested germplasm was from diverse origins. Other evidences confirm that one cannot heterotically group germplasm based only on the genetic distances. This observation was also made by Aguiar et al. (2008).

A novel method that combines both SCA and GCA in a testcross mating design was proposed by Fan et al. (2009) and named *heterotic groups' specific and general combining ability* (*HSGCA*). Basically, the method has four steps after estimating the normal individual GCAs and SCAs effects of each line, tester and testcrosses: 1) to calculate individual *HSGCA* effects ($HSGCA_i = g_i + s_{ij}$); 2) to place all lines with negative *HSGCA* effects into the same heterotic groups as their testers. A line can be assigned to more than one heterotic group; 2) to keep the line to the assigned heterotic group if its *HSGCA* effect is the smallest and remove it from other heterotic groups; and 3) to NOT assign a line to any heterotic group if its *HSGCA* effects are positive with all testers, because it might belong to a completely different heterotic group that is not represented by the testers used.

Because of the unlimited genetic combinations between any two inbred lines, no heterotic group classification method is fully perfect. However, it is still possible to adopt a good heterotic group classification method. A good heterotic group classification method is one whose classified heterotic groups allow inter-heterotic group crosses to produce more superior hybrids than the within group crosses. Fan et al. (2009), compared the breeding efficiency of the three heterotic group classification methods, namely molecular marker-based, pure SCA from diallel crosses and the newer *HSGCA* methods. They defined "breeding efficiency" as percentage of superior

high-yielding hybrids obtained across the total number of heterotic crosses, and they concluded that the *HSGCA* method was more reliable and efficient than the other two methods.

1.8 Conclusion

From the reviewed literature, it is envisaged that the use of unimproved seeds is the most important socio-economic constraint in maize production under poor farmers' field conditions and a joint effort of the extension services, seed companies and NGOs can help educate the farmers and solve associated problems. Field pests and foliar diseases are the main biotic constraints and they are already being addressed by different breeding projects in the region. Although breeding for improved grain yield under low soil fertility has not achieved spectacular results, research is continuing since 1995. Currently, there are three regional projects, one on breeding and two on agronomy, attempting to address the low soil fertility problem.

In contrast, combined heat and drought stress tolerance in maize is a relatively new research area and little has been done in terms of genetic studies and practical breeding. Only two final studies on genetic variability for combined heat and drought stress tolerance by CIMMYT have been reported (Cairns 2013). Of course, the two studies could not include all lines that are in use by different national programmes in the region, in general, and in Mozambique, in particular. Large genetic variability was reported among the 300 lines investigated in the latest study and only 10 (3 %) inbred lines were identified as candidate donors for combined heat and drought stress tolerance. On gene action, only two studies for heat tolerance alone have been published and none on combined heat and drought stress tolerance. In one study, both additive and non-additive gene actions were reported to be important and it did not indicate which one was found predominant. In the second one, it was reported predominance of the dominance type of gene action for grain yield and all other traits studied. For a practical breeding approach, it is very important to have knowledge about the major traits associated with grain yield under combined heat and drought stress conditions. Such information was not found during the literature search. Also, it has not been reported whether combining ability and heterotic orientation of maize lines would change or remain the same when growing conditions change from non-stressed to combined heat and drought stress. Therefore, specific research is required in order to fill these gaps in information for scientists addressing the challenge caused by climate change worldwide, especially in the tropical lowland environments.

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2. CHAPTER 2. Genetic variability for combined heat and drought stress tolerance in tropical lowland maize germplasm

Abstract

Poor rainfall distribution and temperatures above the optimum threshold limit for maize (*Zea mays* L.) are the most limiting production constraints in tropical and subtropical environments. Maize breeding programmes that address tolerance to these abiotic stresses are recommended. Therefore, this study was designed to assess genetic variability for combined heat and drought stress tolerance in the maize germplasm in Mozambique. One hundred and eight maize inbred lines were assembled from the National Programme of Mozambique, International Centre for Maize and Wheat Improvement and International Institute for Tropical Agriculture for this study. Experiments were conducted during the 2014 hot and off-rain season at both Chiredzi and Save Valley, in Zimbabwe, and 2014/15 main season at Chókwè, in Mozambique. Experimental design was a 9 × 12 α-lattice with two replications per experiment grown under managed drought and fully-irrigated conditions at each site. Significant differences among genotypes for days to anthesis, anthesis-silking interval, plant height, leaf senescence, number of plants at harvesting, ear aspect, grain yield and grain yield rank under the four environments were detected. Number of ears plant^{-1} was not significant at Chiredzi ($p > 0.05$) and ear position was only significant at Chókwè under unstressed condition. Combined environment analysis detected highly significant effects due to environment and genotype effects for the majority of traits, except anthesis-silking interval for which was significant at $p < 0.05$, implying that experimental growing conditions and genotypic performance were different. Genotype × environment interaction mean squares were significant only for leaf senescence, grain yield and days to anthesis, suggesting that differential response of genotypes due to changes on growing conditions were pronounced only for these three traits. Maize inbred lines tolerant to the combined heat and drought stress were identified. Inbred lines IL-92, IL-107, IL-53 and IL-101, with good grain yield, lower lodging and ear aspect, were outstanding and were considered stronger candidates for future use in breeding for combined heat and drought stress tolerance under subtropical lowland environments.

2.1 Introduction

Heat and drought stresses occur simultaneously during the main cropping season (rain and warm) in many tropical environments, and this has been a matter of concern among farmers and public leadership. In Mozambique, the National Institute for Natural Disasters' Management (INGC) published a comprehensive report on the analysis of climate changes and it concluded that there was an increase in the average and frequency of maximum temperatures, while the frequency of rainfall was decreasing (INGC, 2010). Using maize crop data, Harrison et al. (2011) investigated the impact of temperature changes during the 1979/80 - 2008/09 period on maize production in Mozambique. They reported that there was a reduction in the length of vegetative stages and the reproductive organs appeared significantly earlier as a direct consequence of increased average mean temperatures. This may have a negative impact on future maize yields in the majority of the Mozambican agro-ecologies that are characterized as hot environments.

The optimum temperature range for maize is between 32 to 37^{o}C as reviewed by Sánchez et al. (2014) and yield losses due to heat stress are result of several negative effects on the plant body and system, varying depending on the stage of the crop. Karim et al. (2000) observed that, at seedling stage, supra-optimal temperatures weaken the plantlets and quickly turn leaf colour from dark-green to pale-green or even yellow, indicating an accelerated senescence. During the vegetative stage, one of the negative effects is leaf injuries (Mahmood et al., 2010), easily observed like "leaf firing", which leads to reduced photosynthetic area (Edreira and Otegui, 2012). High temperatures also shorten vegetative stage by accelerating plant development (Reynolds et al., 2016) and also shorten grain filling stage (Edreira and Otegui, 2012). When heat stress occurs during the flowering period, pollination can be seriously affected due to reduced pollen viability (Schoper et al., 1987a) and rapid silk desiccation (Schoper et al., 1987b) with a decrease in kernel set. Because of reduced photosynthetic leaf area, grain filling stage is negatively affected and final kernel weights are reduced with final consequence of lowered grain yields.

Therefore, selection of maize germplasm tolerant to combined heat and drought stress under field conditions is of uppermost importance as one of the strategies to help maintain or even improve grain yields in environments and seasons characterized by temperatures above the optimum range for the crop and unpredictable rainfalls.

Existence of a large pool of genetic variability is a pre-requisite for a successful breeding programme for any trait in order to optimize response to selection. Maize improvement for drought tolerance has received special attention, in general, from many breeding programmes in countries located in tropical and subtropical climates (Bänziger et al., 2000; Bänziger et al., 2004; 2006; Derera et al., 2008; Magorokosho and Tongoona, 2004; Makumbi, 2005; Makumbi et al., 2011; Messmer et al., 2009; Mhike et al., 2011; Mhike et al., 2012; Ribaut and Ragot, 2007; Ribaut et al., 2009; Vivek et al., 2009), and in Mozambique (INIA, 2001) in particular.

In the case of heat, Bai (2003) observed significant variation for all heat tolerance related traits among 179 recombinant maize inbred lines developed from a cross between a heat tolerant and heat susceptible inbred lines. In another study by Khodarahmpour et al. (2011), variations among inbred lines as well as among hybrids for heat stress tolerance were detected and the best lines and hybrid combinations for heat tolerance were identified. On the other hand, Lu et al. (2011) screened of 550 inbred lines for drought tolerance in Tlaltizapan-Mexico, a tropical environment, under well-watered and water-stressed conditions. The average maximum temperature during the growing experiment was 33^{o}C. The study successfully identified inbred lines that showed strong drought tolerance under such a warm and dry environment. This may be an indication that the identified drought tolerant lines also carried important genes that helped the plants withstand the environmental conditions that were characterized by a combination of drought and heat stress.

The majority of the available maize lines at the Mozambique Institute for Agricultural Research (IIAM) were developed using drought tolerant (DT) populations from CIMMYT and others were directly introduced from CIMMYT and IITA as drought tolerant fixed lines for immediate creation of drought tolerant varieties. However, none of the locally developed lines have been screened for tolerance to combined heat and drought stress. In addition, the performance of the introduced DT lines from CIMMYT under combined heat-drought stress conditions is still unknown. Therefore, the purpose of this study was to assess genetic variability for combined heat-drought stress tolerance among the available maize inbred lines in Mozambique.

2.2 Materials and Methods

2.2.1 Maize germplasm

A total of 108 maize inbred lines (ILs) from IIAM (IL-1 to IL-82 and IL-103 to IL-105), CIMMYT (IL-83 to IL-100 and IL-106 to IL-108), and IITA (IL-101 and IL-102) were evaluated (Appendix 2.1). IIAM lines were developed under the Mozambican environmental conditions using drought tolerant populations introduced from CIMMYT-Zimbabwe during the Rockefeller Foundation Project period (2004 to 2007). Some of the lines from CIMMYT were introduced as parents of hybrid varieties released in Mozambique and others came under the Drought-Tolerant Maize for Africa (DTMA) and the Insect-Resistant Maize for Africa (IRMA) collaborative regional projects. Seeds were multiplied at Chókwè Research Station in 2012 using "sibbing" pollination method and then treated with Actelic insecticide and kept in the cool storage room.

2.2.2 Experimental sites, design and field management

The trial was conducted in Zimbabwe, at Chiredzi (21^{o} 02' S, 31^{o} 37' E, 420 m.a.s.l.) and Save Valley (20^{o} 15' S, 32^{o} 22' E, 455 m.a.s.l.) and in Mozambique at Chókwè (24^{o} 32' S, 33^{o} 00' E, 33 m.a.s.l.) experimental stations. These are subtropical lowland environments which fall under 800 m altitude according to the CIMMYT classification system. Therefore results from the study will be representative of the subtropical lowland conditions and weather information during the growing period of the experiments at each site are summarised in Figures 2-1, 2-2 and 2-3.

The trials were laid out as 9 × 12 alpha-lattice design with two replications at each site. Plot sizes were single 4 m rows with spacing of 0.75 m between planting rows and 0.25 m between stations within a row. Two seeds per station were sown and thinned to one plant per station after emergence was complete, resulting in 17 plants plot^{-1} which corresponded to a plant population density of approximately 53,333 plants ha^{-1}. Two border-rows were planted at each side of the range and were treated the same as the experimental plots.

The treatments were:

i. Heat alone and combined heat and drought stress conditions at Chiredzi and Save Valley sites. At Chiredzi, the experiments were sown on 06 August and at Save valley on 25 September, 2014 which is the off-rain season and hottest period in that region. Mineral

fertilization was applied at each site. A total of 40 kg N ha^{-1} urea and 60 kg P ha^{-1} as triple calcium superphosphate were applied at sowing. A second application of N (60 kg N ha^{-1}) was applied five weeks after emergence. At each location there were two experiments under different water-regimes as follows: fully-irrigated and managed-drought. Irrigation was done with sprinklers at the two sites and water was applied until physiological maturity for the fully-irrigated conditions while for managed-drought, irrigation was stopped five days after application of top-dressing fertilizer (40 days after emergence). Therefore, two different stress categories were experienced: 1) heat stress alone = well-watered and hot (WWH) and 2) managed drought and heat (MDH) stress conditions.

ii. Only a **Random-drought condition** (not the combined heat and managed drought) was observed at Chókwè Research Station because sowing was only possible on 07 November, 2014, when rains had started. Drought spells occurred during the final period of flowering stage and grain filling. Consequently, mild and random-drought stress (RDS) was experienced. In Chókwè, basal fertilizer at the rate of 40 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} and top dressing with 60 kg N ha^{-1} were applied.

iii. Optimum condition: Another experiment was established at Chókwè with optimum conditions. These conditions differed from the RDS by having supplemental irrigation throughout until physiological maturity.

2.2.3 Data collection

Recommended procedures by CIMMYT (CIMMYT, 1985; Magorokosho et al., 2008) were followed for the assessment of most of the traits and data were collected on per plot basis. The two plants from each end of the row were discarded as border plants in all observations. Recorded variables varied from site to site. Nine variables, namely days to anthesis (AD), anthesis-silking interval (ASI), average plant height (PH), average ear placement (EPO) leaf senescence (LS) final number of plants (NP), average number of ears $plant^{-1}$ (EPP), ear aspect (EA) and grain-yield (GY) were recorded. Plant heights were not measured at the stressed environment of Chókwè and LS was not recorded at Save Valley.

Weather information during the experiment growing periods at the three experimental sites:

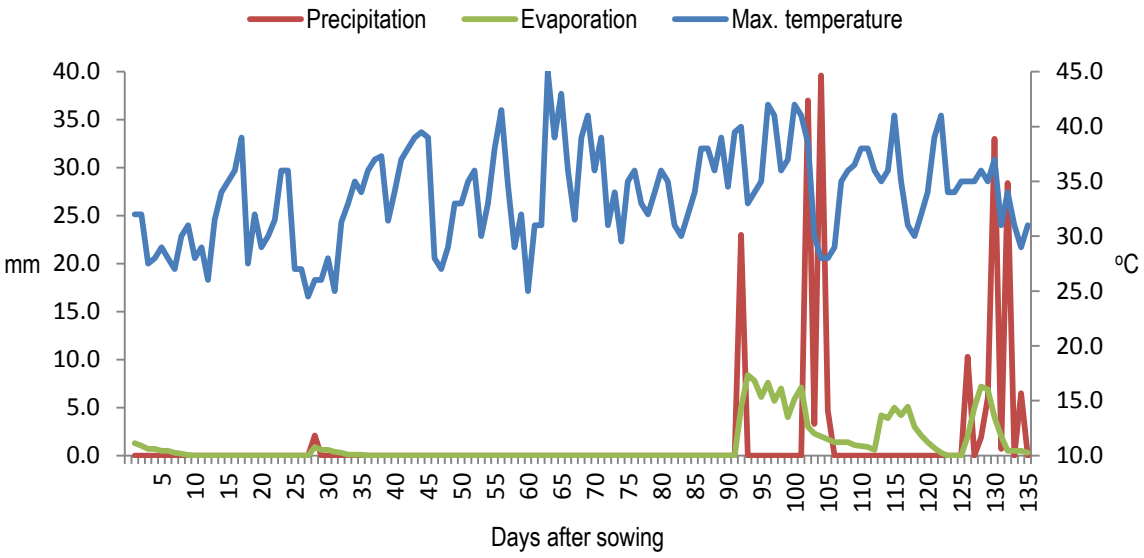

Figure 2-1. Daily precipitation, evaporation and maximum temperature during the experiment growing period at Chiredzi.

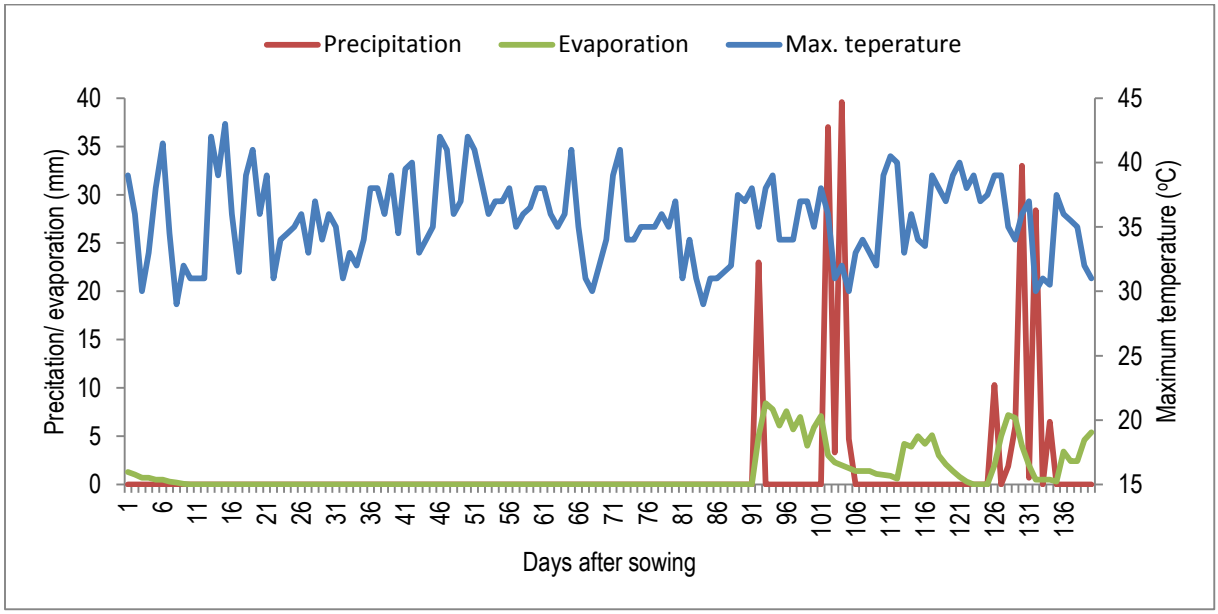

Figure 2-2. Daily precipitation, evaporation and temperature during the experiment growing period at Save Valley.

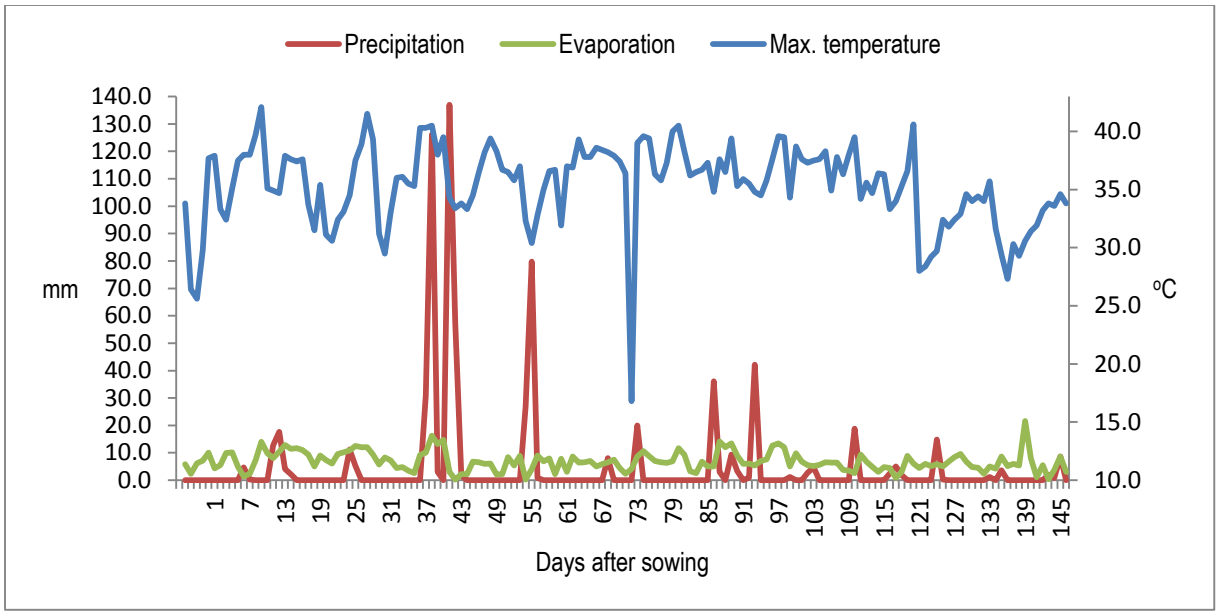

Figure 2-3. Daily precipitation, evaporation and temperature during the experiment growing period at Chokwe.

2.2.4 Data analysis

For data analysis single environment (stress within location) analyses were carried out using REML procedure in Fieldbook-IMS statistical software developed by CIMMYT (Bänziger et al., 2012). A combination of mixed model and spatial analyses were employed as recommended by Bänziger et al. (2000) as a measure to reduce experimental error in heterogeneous field trials. Inbred lines (genotypes) were taken as fixed and incomplete blocks were considered as random factors. Across environment analyses were done in SAS version 9.2 following PROC GLM. Locations and genotypes were treated as fixed, while stress and all interactions were considered random factors. Adjusted genotypic means from the single environment analyses were used (Pimentel-Gomes, 2009). Therefore, the resulting mathematical model for the analysis was as follows:

$$Y_{ijkm} = \mu + l_i + s(l)_{ij} + (s \times l)_{ij} + g_k + (g \times l)_{ki} + (g \times s)_{kj} + (g \times l \times s)_{kij,}$$ [Equation 2-1]

Where Y_{ijkm} is the individual adjusted mean estimated in environment (location × stress) for particular variable; μ is the grand mean; l_i is the estimate of the i^{th} location effect; $(sl)_{ij}$ is the estimate of the j^{th} stress category effect within i^{th} location; $(s \times l)_{ij}$ is the estimate of the stress × location interaction effect; g_{ijk} is the estimate of the k^{th} genotype (inbred line) effect in j^{th} stress at i^{th} location; $(g \times l)_{ik}$ is the estimate of the genotype × location interaction effect; $(g \times s)_{jk}$ is the

estimate of the genotype × stress interaction effect; and $(g \times s \times l)_{ijk}$ is the estimate of the genotype × location × stress interaction effect.

Significance of location and stress mean squares were tested against the mean square of their interaction while genotype, g × s and g × l mean squares were tested against the third degree interaction (g × s × l) mean square. T-test was used for mean comparisons.

Secondary traits, GY-rank under stress and geometric mean productivity were used to identify genotypes with tolerance to both drought and heat stresses. Geometric mean productivity (GMP), as applied by Anwar et al. (2011), Khodarahmpour et al. (2011) and Papathanasiou et al. (2015) was calculated as follows:

$$GMP = \sqrt{Y_p \times Y_S}$$, [Equation 2-2]

Y_p and Y_s represent the yields of each cultivar under well-watered and stressed conditions, respectively. Inbred lines with highest GMP values were considered stress tolerant.

At individual environment, selection index (SI) was calculated and the following formula was applied:

$$SI = b_1P_1 + b_2P_2 + ... + b_nP_n$$, [Equation 2-3]

$$P_i = \frac{(X_{ij} - m_i)}{s_i}$$, [Equation 2-4]

where P_i was the observed standardized value of the trait i and b_i was the weight given to that trait. Parameters m_i and s_i were the mean and standard deviation of trait i, and x_{ij} was the value of the trait i measured on genotype j.

Different selection weights were given to different traits for which treatment effects were significant in the ANOVA. The magnitude of the weights was decided depending on the importance of a particular trait for stress tolerance (Bänziger et al., 2000). As the primary trait, grain yield (GY) was given the maximum weight of 10. Therefore, the weights for the different traits in this study were as follows: grain yield =10; rank = 6; anthesis date = 4; anthesis-silking interval = 5; leaf senescence = 5; plant height = 3; lodging = 4; number of plants = 3; ear placement = 4; ears plant^{-1} = 5; ear aspect = 5; and husk cover = 3. The applied selection intensity was 10%.

Additive main effects and multiplicative interaction (AMMI) and genotype main effects and genotype × environment interaction (GGE) biplots, using adjusted means, were generated in Genstat 14 (Payne et al., 2011) to examine the genotypic relationships with the environments (Yan and Hunt, 2001; Yan and Tinker, 2006).

2.3 Results

For the variables measured, a combination of spatial analysis with mixed model using incomplete blocks as random and inbred lines as fixed factors resulted in best linear unbiased estimates (BLUEs) for each genotype at each experiment (Appendix 2-2 (a), (b), (c), (d), (e), (f)).

The grand means for grain yield (GY) were similar under the two experiments (isolated-heat (WWH) and managed heat-drought (MHD) stress conditions within the same location at Chiredzi (0.590 and 0.819 t ha^{-1}) and Save Valley (1.015 and 1.536 t ha^{-1}), but they differed in the two experiments conducted at Chókwè (1.299 t ha^{-1} under random-drought and 3.045 t ha^{-1} under optimum conditions). Therefore, a combined pre-analysis using BLUEs from the six single experiments conducted under two water-regimes at Chiredzi, Save Valley and Chókwè was performed and results are shown in Appendix 2-2.

The analysis using BLUEs revealed that location effects were not statistically significant for the GY across experiments ($p > 0.05$). It was confirmed that water-regime effects at the individual experiment level within location were statistically insignificant ($p > 0.05$), but the genotypic effects were still highly significant ($p < 0.001$). The Zimbabwe locations were then treated as two environments with two replications each using BLUEs, while the two different water-regimes at Chókwè were kept separate, with two replications each. This resulted in four environments namely; severe heat-drought stress (SHDS) at Chiredzi (average grain yield of 0.694 t ha^{-1}), moderate heat-drought stress (MHDS) at Save Valley (average grain yield of 1.276 t ha^{-1}), random-drought stress (RDS) and non-stressed condition (OPT) at Chókwè. Analyses were carried out with these new defined environments. As explained before, RDS was the non-irrigated experiment affected by unpredicted showers at Chókwè, while OPT was the fully and well-watered experiment.

2.3.1 Single environment analysis

Results from the four single environment analyses are summarized in Table 2 and adjusted genotypic means are presented in Appendix (a), (b), (c) and (d). The results revealed that, under the SHDS condition achieved at Chiredzi, the genotypic means were significantly different at $p < 0.001$ for AD, LS, NP, EA and GY. For GY-rank and SL the means were statistically significant at $p < 0.01$, while for ASI the significance was only at $p < 0.05$. Means for PH, EPO and EPP were not statistically different ($p > 0.05$). Based on the selection index involving the variables in which means were found to be significant, seven inbred lines were selected at Chiredzi. These included IL-31, IL-92, IL-108, IL-107, IL-11, IL-85 and IL-86 in this order.

At Save Valley, where stress was moderate (MHDS), only means for EPO were not statistically different. For ASI, PH and NP the differences were at $p < 0.05$, and for EA were highly significant ($p < 0.01$). More pronounced differences were detected among means for AD, EPP, GY and GY-rank ($p < 0.001$) at this environment. Superior inbred lines identified from this were IL-92, IL-107, IL-108, IL-16 and IL-103.

Under the RDS (stressed environment of Chókwè), genotypic means were statistically different at $p < 0.001$ for most of the measured variables apart from LS and NP ($p < 0.05$). At this environment, the set of selected lines included IL-92, IL-102, IL-53, IL-101, IL-33, IL-76, IL-44, IL-100, IL-64, IL-69 and IL-75. On the other hand, under non-stressed condition (OPT), at Chókwè, differences among the genotypic means were highly significant ($p < 0.001$) for almost all the variables except NP ($p < 0.01$). In addition, eleven lines were selected and these were IL-101, IL-102, IL-53, IL-47, IL-10, IL-20, IL-75, IL-31, IL-22, IL-78 and IL-82.

2.3.2 Combined analysis with four environments

Combined ANOVA of BLUEs from the four defined environments was highly significant ($p < 0.001$) for environmental and genotypic effects for almost all the variables analysed (Table 2.2)), except ASI whose genotypic variance was only significant at $p < 0.05$, and EPO not statistically significant ($p > 0.05$). The GEN × ENV interaction effects were statistically significant only for GY and LS ($p < 0.001$), and AD ($p < 0.05$). Since GEN × ENV interaction was significant, genotypic means for GY, LS and AD were not averaged across environments but the rest of the variables were (Appendix 2.4 (a), (b), (c), (d) and (e)).

Table 2-1. Results from statistical analyses of 108 maize inbred lines evaluated in four different environments in 2014 – 2015.

Environment	Trait	AD (days)	ASI (days)	PH (cm)	EPO (ratio)	LS (1-9)	SL %	NP (#)	EPP (ratio)	EA (1-5)	GY (t ha^{-1})	GY-rank (rank)
Severe heat-drought stress (SHDS) = Chiredzi (410 m.a.s.l.)	Mean	67.761	3.307	162.058	0.505	6.107407	3.615	15.469	0.510	4.301	0.694	57.020
	SE	2.260	2.957	14.854	0.065	0.730	5.134	1.000	0.158	0.294	0.326	20.459
	LSD	4.482	5.862	29.449	0.129	1.447	10.178	1.982	0.313	0.583	0.646	40.563
	Min	59.300	-0.900	138.000	0.400	3.450	-2.800	12.240	0.150	3.310	0.080	14.390
	Max	79.900	11.050	188.000	0.630	7.850	19.950	17.060	0.830	4.940	1.800	102.770
	Signf.	***	*	ns	ns	***	**	***	ns	***	***	**
Moderate heat-drought stress (MHDS) = Save Valley (400 m.a.s.l.)	Mean	70.058	1.922549	122.111	0.456	-	-	12.83294	0.668	3.66649	1.276	54.098
	SE	2.024	1.73739	14.280	0.053	-		1.868496	0.171	0.531557	0.407	18.929
	LSD	4.013	3.445	28.311	0.105	-	-	3.704	0.338	1.054	0.806	37.528
	Min	63.15 -	-0.350	89.000	0.400			7.820	0.300	1.990	0.500	2.475
	Max	79.600	5.900	156.000	0.500	-	-	15.630	1.100	5.050	3.480	93.270
	Signf.	***	*	*	ns	-	-	*	***	**	***	***
Random drought stress (RDS) =Chokwe (33 m.a.s.l.)	Mean	66.200	7.003	-	-	8.428	30.563	14.744	1.121	3.345	1.299	47.253
	SE	0.934	0.797	-	-	0.695	16.150	1.737	0.180	0.458	0.261	19.180
	LSD	1.851	1.581	-	-	1.377	32.019	3.443	0.357	0.909	0.517	38.022
	Min	60.560	3.100			5.080	2.750	9.610	0.630	1.890	0.260	-7.370
	Max	73.600	10.640	-	-	9.110	87.050	19.380	1.680	4.810	2.310	102.740
	Signf.	***	***	-	-	*	***	*	***	***	***	***
Non-sstressed (OPT) = Chokwe (33 m.a.s.l.)	Mean	56.246	2.244	193.364	0.560	8.263	-	15.685	1.166	3.617	3.045	53.390
	SE	1.116	0.944	16.600	0.048	0.456	-	1.998	0.154	0.604	0.603	17.130
	LSD	2.212	1.872	32.908	0.095	0.903	-	3.961	0.305	1.197	1.196	33.958
	Min	48.370	-1.980	140.560	0.430	1.440		12.550	0.370	2.270	0.300	-6.320
	Max	63.940	5.110	238.110	0.710	8.980	-	21.820	1.760	5.050	6.090	107.650
	Signf.	***	***	***	***	***	-	**	***	***	***	***

AD = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **LS** = leaf senescence; **SL** = stem lodging; **NP** = number of plants; **EPP** = ears per plant; **EA** = ear aspect; **GY** = grain yield; **GY**-rank = grain yield rank.
******* = significant at 0.1% probability; ****** = significant at 1% probability; ***** = significant at 5% probability; **ns** = not significant.

Table 2-2 Mean squares from the ANOVA of 108 maize inbred lines tested at Chiredzi, Save Valley and Chókwè in 2014/15

Source	DF	GY	GY-Rank	EPP	EA	DF	AD	DF	ASI	DF	PH[b)]	EPO	DF	LS[b)]	DF	NP
ENV	3	134.334***	2274.888***	15.767***	28.093***	3	4967.353***	3	643.306***	2	199773.220***	0.408***	2	271.569***	3	320.350***
REP(ENV)	2	8.964***	827.531	1.375***	27.812***	2	15590.742***	2	378.251***	2	25925.873***	0.774***	1	1.402	2	468.339***
Genotype (GEN)	107	1.150***	2086.911***	0.075***	0.759***	107	45.338***	107	5.637*	107	505.461***	0.004	107	2.553***	107	4.678***
GEN X ENV	321	0.271***	386.491*	0.031	0.224	321	5.756*	320	3.996	214	176.673	0.003	214	1.340***	321	2.510
ERROR	213[a)]	0.136	388.297	0.027	0.185	208[a)]	4.613	196[a)]	5.967	214[a)]	212.274	0.004	107[a)]	0.533	214[a)]	2.245
Mean		1.381	53.808	0.775	3.816		66.316		3.305		152.341	0.496		7.227		14.505
R^2		0.955	0.810	0.921	0.880		0.982		0.806		0.923	0.821		0.951		0.872
SE		0.389	20.818	0.174	0.454		2.269		2.581		15.392	0.063		0.771		1.583
LSD (0.05)		0.768	41.036	0.342	0.896		4.473		5.090		30.340	0.124		1.529		3.120

[a)]the difference on the number of DF are due two different missing values; [b)]traits that were not measured in one of the environments.

ENV = environments; **REP(ENV)** = replications within environment; **GEN** = genotype; **GEN × ENV** = genotype-by-environment interaction; **DF** = degrees of freedom.

GY = grain yield; **GY-Rank** = plot-to-plot grain yield rank; **EPP** = ears per plant; **EA** = ear aspect; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **LS** = leaf senescence; **NP** = number of plants at harvest date.

For GY, AMMI and GGE biplot analyses were used to check the environmental differentiation and the genotypic adaptability to different environments. Like it was observed in the ordinary combined ANOVA reported earlier on, environments, genotypes and genotype × environment interaction effects were highly significant ($p < 0.001$) on AMMI ANOVA (Table 2.3). Total sum of squares due to environment was more than 66% of the total variation observed while genotypes and genotype × environment sum of squares were about 18% and 14%, respectively. Environment sum of squares were almost five times more than the total interaction effects while genotypes contributed only 1.32 times. The first principal component (PCA1) was highly significant ($p < 0.001$) but the second (PCA2) was not ($p > 0.05$), therefore, AMMI biplot was constructed using PCA1 scores of genotypes and environments against their main effects.

Table 2-3. AMMI ANOVA for grain yield using BLUE means of 108 maize inbred lines evaluated under SHDS, MHDS, RDS and OPT environments.

Source	DF	SS	MS	F_obs	F_prob.
Genotypes	107	92.42	0.86	3.95	<0.001
Environments	3	335.08	111.69	511.29	<0.001
Interactions	321	70.12	0.22	3.67	<0.001
IPCA 1	109	55.82	0.51	9.02	<0.001
IPCA 2	107	8.35	0.08	1.37	0.0520
Residuals	105	5.96	0.06		
TOTAL	536	503.58			

BLUE = best linear unbiased estimetes

The top 10 ranked inbred genotypes (less than 10% of selection intensity) from AMMI are shown in Table 2.4. It is observed that genotype ranking changed from one environment to another. Only IL-92 and IL-107 are selectable in the four environments, while IL-31 performed better under SHDS, although it was good also at the RDS and OPT environments of Chókwè. IL-108 was not selected in the OPT environment only while IL-101 and IL-102 were not selected in the SHDS only.

Table 2-4. First 10 (selection intensity < 10%) AMMI selections per environment

ENV	Mean	Score	Selected inbred lines									
SHDS	0.694	0.962	31	107	99	43	108	92	11	76	16	22
MHDS	1.276	0.750	92	102	107	16	108	101	33	100	62	17
RDS	1.299	0.647	92	107	108	101	31	53	102	43	76	16
OPT	3.045	-2.359	53	92	47	101	102	10	31	38	107	54

SHDS = severe heat-drought stress; **MHDS** = moderate heat-drought stress; **RDS** = random drought stress; **OPT** = unstressed

In the biplot (Figure 2-1), AMMI classified the three stressed environments in the same quadrant characterized by lower main effects and very small (less than a unit) positive PCA1 scores, and the OPT environment was allocated to the quadrant characterized by high main effects (approximately 2.5) negative PCA1 scores. The majority of the genotypes were plotted around the origin and very far from the OPT environment.

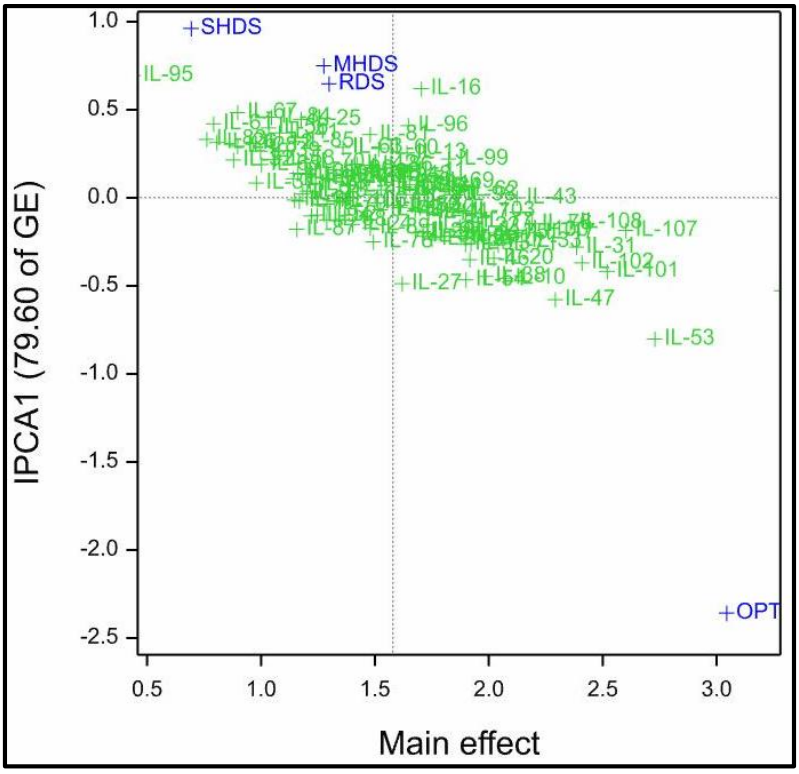

Figure 2-1. AMMI main effects vs PCA1 scores biplot visualisation of genotype × environment interaction between 108 maize inbred lines and four (SHDS, MHDS, RDS and OPT) environments for grain yield.

However, GGE biplot (Figure 2-2) placed the two Chókwè environments (OPT and RDS) at very close positions of [PCA1; PCA2] coordinates and it classified them into the same sector with MHDS. The most stressed environment, (SHDS) was separated from the rest. Genotype IL-92 was plotted very close to the arrow vector head, exactly on the central circle line (Figure 2-2). Genotypes IL-108 constituted the vertex of the polygon at the mega-environment where SHDS was plotted (Figure 2-3). The other genotype very closer to SHDS was IL-31. The sector where OPT, RDS and MHDS environments are classified has two polygon vertex genotypes: The furthest vertex genotype of the polygon is IL-92 and the second one is IL-102. Genotype vertex IL-92 connected IL-108 vertex from the previous sector and IL-102 vertex.

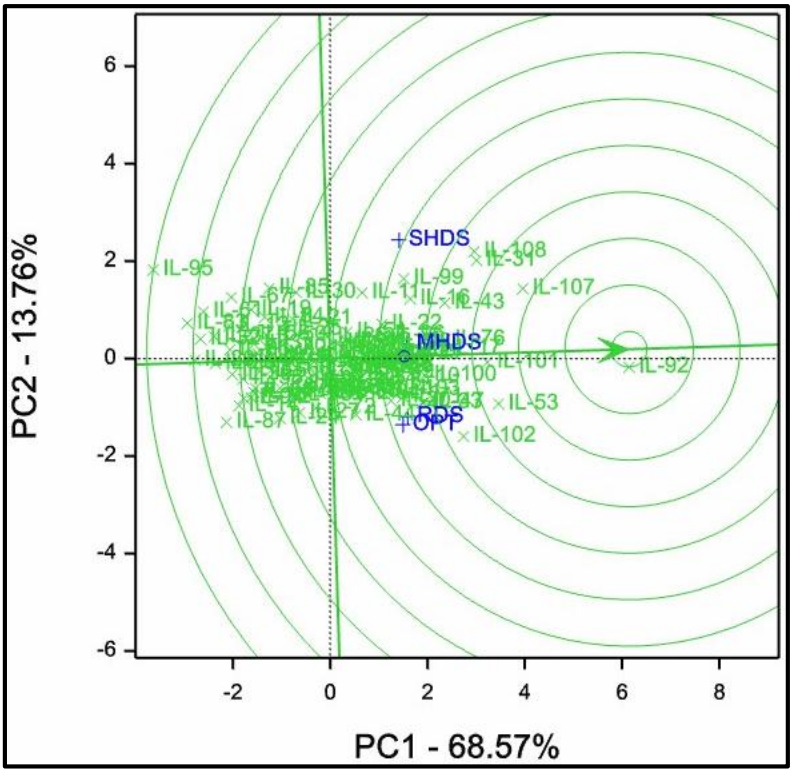

Figure 2-2. GGE biplot visualisation of genotypic performance and stability from genotype × environment interaction between 108 maize inbred lines and four (SHDS, MHDS, RDS and OPT) environments for grain yield.

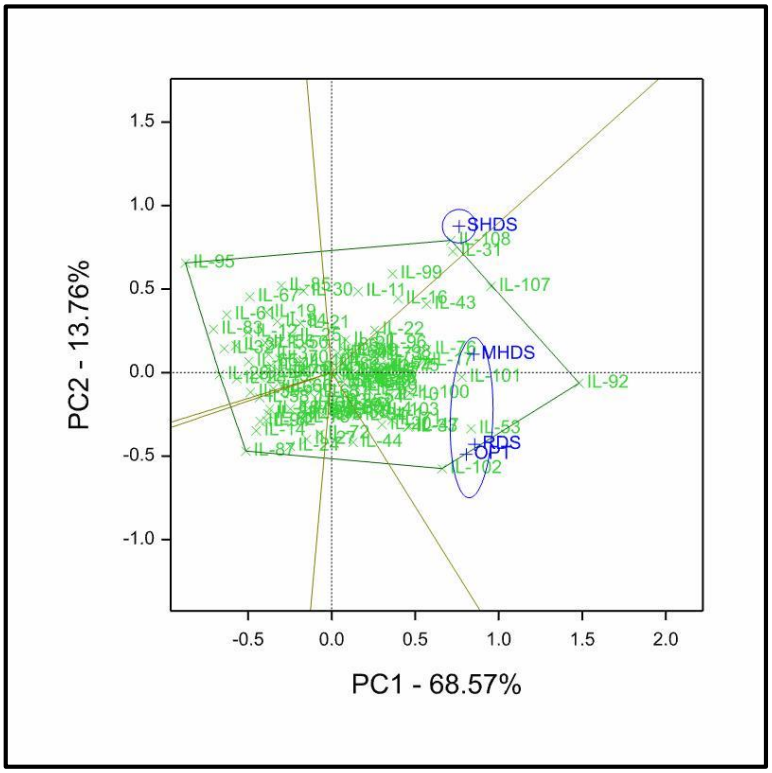

Figure 2-3. GGE biplot visualisation of genotypic winning at specific environment from genotype × environment interaction between 108 maize inbred lines and four (severe heat and drought stress, moderate heat and drought stress, random drought stress and optimum) environments for grain yield.

2.3.3 Final selection

Final identification of tolerant genotypes for combined heat-drought stress was made using combination of results, including geometric mean productivity (GMP). A total of 15 inbred lines were selected (Table 2.5). Out of the 15, eight were sourced from IIAM, two from IITA and the rest are from CIMMYT.

Table 2-5. Selected inbred lines for combined heat and drought stress based on GY-Rank, and geometric mean productivity (GMP) across environments

Inbred line	Pedigree	Origin	GY-Rank (Avg)	GMP			
				SHDS vs MHDS	SHDS vs OPT	MHDS vs OPT	GMP-Avg
92	CZL04007	CIMMYT-Zimbabwe	6.4	1.082	1.111	1.164	1.119
107	DTPYC9-F46-1-2-1-1-B	CIMMYT-Mexico	11.7	1.073	1.104	1.131	1.103
53	MATUBASG-14-1-4-3-3-1-9-5-B	IIAM-Mozambique	15.5	1.035	1.098	1.129	1.087
101	IITA1	IITA	15.6	1.046	1.092	1.125	1.087
102	IITA2	IITA	23.3	1.013	1.049	1.128	1.063
31	ZM521-13-3-2-3-1-1-B*2-B	IIAM-Mozambique	24.5	1.059	1.111	1.109	1.093
47	ZM621-24-3-1-1-1-1-1-1-B	IIAM-Mozambique	24.9	1.015	1.070	1.116	1.067
76	CHINACAFS-75-1-1-3-1-B	IIAM-Mozambique	25.5	1.039	1.080	1.105	1.075
33	ZM521-15F	IIAM-Mozambique	27.5	1.014	1.052	1.111	1.059
108	DTPYC9-F46-1-2-1-2-B	CIMMYT-Mexico	28.1	1.071	1.102	1.122	1.098
10	ZM421-12-1-1-2-2-1-6-1-B	IIAM-Mozambique	29.5	0.999	1.080	1.079	1.053
100	IRMA3 = CML444	CIMMYT-Zimbabwe	30.1	1.025	1.063	1.108	1.065
22	ZM421-22-2-2-1-2-1-4-B*2-B	IIAM-Mozambique	38.9	1.015	1.077	1.076	1.056
16	ZM421-12-3-3-1-4-1-1-B	IIAM-Mozambique	41.3	1.045	1.032	1.067	1.048
86	CML445	CIMMYT-Zimbabwe	53.1	1.004	1.033	1.066	1.034
Average			**52.9**				
Minimum			**6.4**				
Maximum			**89.6**				

GY-Rank = grain yield rank; **GMP** = geometric mean productivity index; **GMP-Avg** = average of GMP from the three contrasted environments; **SHDS** = severe heat and drought stress; **MHDS** = moderate heat and drought stress; **OPT** = optimum.

Lines with lower GY-Rank are stable across different environmental conditions;

Lines with high GMP indices (average) are stress tolerant and performed well under optimum conditions

2.4 Discussion

It is widely accepted that increased mean temperatures during the growing season and simultaneous occurrence of frequent heat waves and drought spells are expected to be a main feature of the maize production environments in the near future. Therefore, development and use of crops resilient to multiple stresses is becoming a priority among scientists (Adolf et al., 2012). Findings from this study support results from recent investigations and reviews on heat stress tolerance which concluded that drought tolerant germplasm may not perform well under combined drought-heat stress conditions (Adebayo et al., 2014; Cairns et al., 2013b; Cairns et al., 2013a; Edmeades, 2013). This indicates that heat stress tolerance should be incorporated in maize breeding programmes as part of the strategy to mitigate the impact of climate change in maize (Barnabas et al., 2008; Bita and Gerats, 2013; Cairns et al., 2012; Cicchino et al., 2010; Kebede et al., 2012; Lobell et al., 2011; Nelson et al., 2009).

Statistically insignificant variances due to stress within location and non-significantly different experimental means for grain yield at Chiredzi and Save Valley where temperatures were very high (Figures 2-1 and 2-2) indicate that combined heat-drought conditions were achieved but separate heat conditions were not. The failure to exclude drought at Chiredzi and Save Valley was due to insufficient water availability from the rivers as a result of prolonged absence of rains in that region. Without a continuous full irrigation schedule in one of the treatments from each location, it was impossible to accurately avoid drought stress and remain with heat stress only.

As a statistical procedure, if contribution of one experimental factor in the total variation is insignificant it can be removed from the model (Pimentel-Gomes, 2009). The decision to consider the two sets from Chiredzi as one experiment, and also those from Save Valley as another one, resulted in statistically significant effects due to differences in environmental conditions for all the variables (Table 2-2). This resulted in categorisation of the four environments as severe heat-drought stress (SHDS) at Chiredzi, moderate heat-drought stress (MHDS) at Save Valley, random-drought stress (RDS) at Chókwè and optimum (OPT) for the unstressed environment at Chókwè. Although RDS was interrupted by some showers that occurred when drought was being experienced at Chókwè, its effect was comparable with MHDS achieved in Save Valley and enough to cause difference with the OPT environment at Chókwè. This was well captured in the AMMI bi-plot (Figure 2-1). AMMI biplot classified the three stressed experimental conditions in the same quadrant, although SHDS was distant from

MHDS and RDS. It was also observed that SHDS and OPT were the most contrasting environments, with OPT having the highest IPCA score. This is an indication that OPT environment produced the largest interaction effects when compared with the rest (Farshadfar, 2008; Reddy et al., 2011; Yan and Hunt, 2001).

Unlike AMMI, GGE biplot separated RDS from MHDS but placed it together with OPT environment (Figures 2-2 and 2-3). This is expected since RDS and OPT environments are from the same location and same season, the only difference being in water-regime. Random drought stress environment was excluded when calculating GMP of the individual genotypes because GGE placed it together with the OPT environment. The OPT environment was useful for comparison purposes and calculating the GMP when selection is targeting both stressed and non-stressed conditions (Khodarahmpour et al., 2011; Papathanasiou et al., 2015). In the present study, the ranking of the genotypes for grain yield changed from one environment to another indicating a cross-over type of genotype × environment interaction (Schulthess et al., 2013).

The average GY-rank plus GMP, AMMI selections and GGE biplot graph had similar outcomes in terms of which genotypes could be selected for combined heat-drought stress condition. The results are in agreement with findings by Khodarahmpour et al. (2011). Genotype IL-92 (CZL04007) was always ranked among the top performers and was the best when GY-rank was averaged across environments. In addition, it produced the best GMP and was the genotype of the furthest vertex between the most stressed (SHDS) and the OPT environments (Figure 2-3 The position of IL-92 very close to the head of the average-environment coordination (AEC) line (Figure 2-2) confirms its stability across environments and potential for high yielding (Yan and Tinker, 2006). This genotype was introduced from CIMMYT-Zimbabwe and is the male parent of the drought tolerant three-way hybrid cultivar (CZH04008) already released in Mozambique.

Under the most stressful environment (SHDS) the vertex genotype was IL-108 (Figure 2-3) indicating that it was the best performer in terms of yield, with IL-31 very close to it. IL-108 (DTPYC9-F46-1-2-1-2-B) with its sister line IL-107 (DTPYC9-F46-1-2-1-1-B) were introduced from CIMMYT as heat-tolerant parents for this research. In fact, IL-108 is the fourth among the top 10 CIMMYT donors for combined heat-drought stress tolerance identified by (Cairns et al., 2013b) from a collection of 300 inbreds. Line IL-31, is an early maturing (drought-scape) line developed in Mozambique from ZM421-flint, a popular drought-tolerant OPV developed by CIMMYT (Chaúque et al., 2004).

Under MHDS, majority of the genotypes were those exhibiting stronger stability across environments. These were those ranked immediately after the most stable and upper-yielder, IL-92. Those are IL-101, IL-100 and IL-76 in this order. Nothing surprising because IL-101 is an introduction from IITA as drought tolerant donor under the Water-Efficient Maize for Africa (WEMA) breeding project, IL-100 is CML444, a famous drought tolerant tester line introduced from CIMMYT-Zimbabwe and L-76 was developed in Mozambique using another OPV developed by CIMMY-Zimbabwe and popularly known in the region as drought tolerant.

Based on its position on the AMMI biplot (Figure 2-1), OPT environment contributed more in the total interaction effect. Although it appears that most genotypes were not in the same quadrant as the OPT environment, AMMI selections (Table 2-4) identified IL-53, IL-92, IL-47 and the two lines from IITA (IL-101 and IL-102). The AMMI selections are in concordance with what can be observed from GGE (Figure 2-3). It was observed (Table 2-4) that selectable lines were not exactly the same under SHDS and the rest of the growing environments of this study indicating that breeding programmes and testing environments should be utilised in order to satisfy farmers in different cropping environments. However, the observed high performance and stability of IL-92 suggests that, if a breeding programme generates large numbers of genotypes and screens them under both stressed and unstressed conditions, it is possible to identify genotypes that can do fairly well under both conditions.

The interest in this study was to identify genetic variability, it is, therefore, necessary to highlight also the weakest genotypes under stress. In this regard, the weaker inbred lines are those ranked above the experimental means for average GY-rank and the average GMP under SHDS, MHDS and RDS (Table 2-5). They were more than 55% but the worst were those easily noticeable on the bottom third of the range for GMP. Some of them could be identified from the GGE bi-plot. These were IL-95, IL-87, IL-26, IL-28, IL-83. It is important to point out that among the worst, there were lines known as drought tolerant in the region (IL-87 = CML489 and IL-83 = CML395) and others from the Mozambican National program (IL-26 and IL-28). The least performer (IL-95 = ZEWAc1F2-300-2-2-B-1-B*5) was also an introduction from CIMMYT-Zimbabwe, used to make hybrids but failed to be released in Mozambique.

2.5 Conclusion

In this study, the main objective was to assess genetic variability for combined heat and drought stress tolerance in the maize germplasm available in Mozambique and assembled from different

sources, as a pre-requisite for a successful combined heat and drought stress tolerance breeding program. The results are conclusive in this aspect: genetic variability for combined heat and drought stress tolerance within the studied inbred germplasm exists as was revealed by the significant genetic variation and consequent significant genotypic differences observed under severe heat-drought stress at Chiredzi and moderate heat-drought stress at Save Valley.

Under severe heat and drought stress, the sister lines IL-108 and IL-107 introduced from CIMMYT as heat tolerant donors, IL-92 from CIMMYT-Zimbabwe as drought tolerant hybrid parent and IL-31 developed in Mozambique exhibited better tolerance.

Under moderate heat and drought stress the most tolerant inbreds were IL-92, IL-101 and IL-100 introduced from IITA as drought tolerant donors, and IL-76 developed in Mozambique.

In contrast, more than 55% did not show genetic tolerance to combined heat and drought stress and the worst were IL-26 and IL-28 developed in Mozambique, IL-83, IL-87 and IL-95 known as drought tolerant, among others.

The tolerant lines are good candidates to be incorporated in the breeding programs for combined heat and drought stress tolerance in sub-tropical lowland environments.

There was also an attempt to determine whether the superior lines under combined heat and drought stress environment were the same under heat or drought environments separately at the locations of this study. Due to insufficient water availability at the irrigation sources at Chiredzi and Save Valley that made it difficult to evaluate under heat alone, it was impossible to effectively isolate the two stresses. Therefore, the reported findings were achieved under combined heat and drought stress environment. Also, due to unexpected light showers and temperatures below 38^{o}C at Chókwè only a moderate drought stress condition was achieved at this location. Based on all this unexpected field conditions, the results from the present research are not conclusive and more research following similar statistical design and procedures is recommended.

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3. CHAPTER 3. Gene action controlling maize grain yield and other agronomic traits under combined heat-drought stress

Abstract

Knowledge of the type of gene action controlling tolerance to combined heat-drought stress is important for maize (*Zea mays* L.) breeding programmes designed to address high temperatures and unreliable rainfall effects. This study was carried out to assess gene action controlling maize grain yield and other agronomic traits under isolated heat alone, drought alone and combined heat and drought stress conditions. Ten inbred lines were used to generate forty-five crosses in a half diallel mating design. These were evaluated during the dry and hot season of 2014, and during the end of the rain season (relatively cooler) of 2015 at Chókwè Research Station, Mozambique. The experiments were conducted under both full irrigation and managed drought conditions during each season, resulting in four environments. The yield reduction due to heat stress alone was 19% of the non-stressed experiment (5.40 t ha^{-1}), while reductions due to drought alone and combined heat and drought stresses were 41% and 59%, respectively, indicating that the combined stress condition was more detrimental than the individual stresses. Significant environment and genotype × environment interaction effects for grain yield revealed that hybrid differentiations changed significantly with the change in experimental growing conditions. Genetic analysis following Griffings' Method 4, model 1 (fixed model) detected significant mean squares due to general combining ability (GCA) under combined stress for grain yield ($p < 0.01$) and other agronomic traits but specific combining ability (SCA) was not significant for grain yield ($p = 0.1697$). Under individual stresses and non-stressed conditions, both general and specific combining ability mean squares were significant for grain yield ($p < 0.001$). The results revealed changes in the types of gene action depending on the environmental conditions. For grain yield, additive gene action was predominant over non-additive and the magnitude of its predominance was stronger under combined stress compared to individual stress conditions, as shown by the ratio of SSgca to SS(gca+sca) which was more than 0.5. For the other traits, additive gene action was also predominant regardless of the environment. The results imply that improvement of tropical maize for combined heat-drought stress tolerance is possible and it can be faster when selection are conducted under combined heat and drought stress conditions than under heat stress alone and/or drought alone.

3.1 Introduction

Heat and drought usually occur simultaneously during the main cropping seasons and sometimes cause complete maize crop failure in many tropical and subtropical environments including Mozambique. Two important aspects have been recognized lately: 1) drought tolerant germplasm may not perform well under combined drought-heat stress conditions (Barnabas et al., 2008; Bita and Gerats, 2013; Cairns et al., 2012; Cicchino et al., 2010; Kebede et al., 2012; Lobell et al., 2011; Nelson et al., 2009); and 2) combined stress effect is more devastating than either the drought effects alone or heat stress effects alone (Cairns et al., 2012; Cairns et al., 2013). These two realizations imply that breeding for combined heat and drought stress will be a prudent strategy in order to mitigate the impacts of global warming.

Knowledge of the inheritance of combined heat and drought stress tolerance is an important pre-requisite for successful breeding aimed at developing cultivars that can cope with this challenging stress. The type and magnitude of gene action governing the phenotypic expression of single quantitative traits has been extensively studied in maize (Hallauer, 2007) but rarely for combined heat-drought stress conditions. Under drought alone, Fu et al. (2008) revealed that dominance was more important than additive effects for plant height, anthesis-silking interval, root weight and grain yield per plant, whereas both additive and dominance effects were almost equally important for leaf emergence rate. In contrast, Betrán et al. (2003a) reported that additive gene action increased with the intensity of the drought stress when tropical maize inbred lines were evaluated. Derera et al. (2008), assessing southern Africa maize inbred lines for gene action controlling grain yield and secondary traits under drought stress and non-stressed conditions, found that additive gene action was predominant in governing the phenotypic expression of most of the traits, especially grain yield, under both stressed and non-stressed conditions. However, the importance of non-additive gene action was more pronounced under non-stressed environments. This suggests that, regardless of the type of germplasm, gene action seems to change depending upon the intensity of drought stress. Similar findings were reported for drought tolerance in maize (Hussain et al., 2009; Makumbi et al., 2011; Meseka et al., 2011; Mhike et al., 2011).

Although the negative impact of heat stress on maize productivity in tropical environments has been recognized for quite a long time, relatively few studies have been conducted on the genetic control of heat stress tolerance in maize compared to studies on drought stress tolerance. This is probably due to the complexity of heat stress assessment under field

conditions. One of the earlier studies by Jorgensen and Nguyen (1995) on heat tolerance in maize reported results from genetic analysis of heat shock proteins (HSPs) correlated with heat tolerance in many species (Hu et al., 2010; Jorgensen et al., 1992). The synthesis of HSPs under heat stress treatment was under the control of a single gene and the inheritance was characterized by three types of intra-allelic interactions (complete dominance, over-dominance and co-dominance). In addition, Tassawara et al. (2007) evaluating hybrids developed by crossing five heat tolerant and five heat susceptible lines in a line × tester mating design under maximum temperatures of 40°C, reported that dominance type of gene action was predominant for all the 13 traits recorded in the study. Additionally, Kaur et al. (2010) investigated hybrids from a 12 × 12 diallel mating design under heat stress (maximum temperatures ranging from 35 to 45^{o} C during the flowering time) and found both additive and non-additive gene action to be involved in the inheritance of all the studied heat tolerance and yield contributing characters. However, only leaf firing was significantly correlated with GY. Leaf firing was also strongly correlated with tassel blast, indicating that the two traits are useful when selecting for genotypes adapted to hot environments.

All the current knowledge about the inheritance of grain yield and other important traits suggests that the predominance of a type of gene action is dependent on the genotypes involved, and on the type and intensity of the stress under which the traits are assessed. Therefore, this study was set up to determine the gene action controlling various traits of maize in hybrids developed from a 10 × 10 diallel mating scheme under non-stressed, isolated heat stress, isolated drought and combined heat and drought stress conditions. The intended targeted stress was from pre-flowering to end of grain filling stages for drought and throughout the entire crop development period for heat stress.

3.2 Materials and Methods

3.2.1 Germplasm

Ten maize inbred lines (Table 3.1) were crossed in a half-diallel mating design to generate 45 crosses in the 2014 dry season. The inbred lines were randomly selected from the 108 materials used in the genetic variability study (Chapter 2) for combined heat-drought stress tolerance of the present study. Firstly, 35 lines were selected and planted in a crossing nursery. Many crosses were generated but only 10 parents succeeded to make all possible combinations

and 45 diallel hybrid progenies were selected. The progenies were evaluated together with three genetic checks, namely CML442/CML312, CML395/CML444 and CML444/CML312 which are recognised as drought-tolerant single cross hybrids from CIMMYT-Zimbabwe (CIMMYT-Zimbabwe).

Table 3-1. Pedigrees of ten maize inbred parents randomly sampled from the available germplasm in Mozambique

Parent #	Pedigree	Origin	Drought
1	ZM421F2FS-16-1-1-2-1-1-1-1-B-B(18)	IIAM-Mozambique	Susceptible
2	ZM521F2FS-15-OLD(33)	IIAM-Mozambique	Medium-tolerant
3	ZM621F2FS-19-4-2-1-1-1-1-B-B(45)	IIAM-Mozambique	Tolerant
4	Suwan8075DMRFS-79-2-1-2-2-B-B-2-B(62)	IIAM-Mozambique	Susceptible
5	(P501SR/P502SR)F2FS-31-1-3-1-2-3-1-1-1(61)	IIAM-Mozambique	Susceptible
6	MatubaSGFS-14-1-4-3-3-1-9-5-B-B(53)	IIAM-Mozambique	Tolerant
7	SYNF2FS-4-6-1-2-1-B(65)	IIAM-Mozambique	Tolerant
8	ZEWAC1F2-300-2-2-B-1-B*5(95)	CIMMYT-Zimbabwe	Medium-tolerant
9	CZL04007(92)	CIMMYT-Zimbabwe	Highly-tolerant
10	NIP20-1-1-B-1-B-B-B(96)	CIMMYT-Zimbabwe	Tolerant

The numbers in brackets at the end of the pedigree correspond to the entry numbers in the Chapter 2 study.

3.2.2 Testing environments and field management

Experiments were conducted at Chókwè Research Station in Mozambique during the hot dry season (Figure 3-1) and at the end of the rainy season, when it was relatively cooler, (Figure 3-2). In each season, two experiments were conducted: one under managed drought-stress and another under fully-irrigated conditions. The managed drought stress experiment during the hot and dry season was classified as combined heat-drought stress (CHDS) and the fully-irrigated one was designated as the heat stress (HS). During the relatively cooler season, the managed drought stress environment was classified as drought stress (DS) and the fully-irrigated one as non-stressed (optimum) environment. Drip irrigation was used and water was supplemented until physiological maturity for fully-irrigated environments while for managed drought stress treatments irrigation was stopped forty days after emergence. Basal fertilizer was applied in all experiments at the rate of 40 kg N, 80 kg P_2O_5 and 40 kg K_2O ha^{-1} using mineral compound 12-24-12 at sowing. Nitrogen fertilizer at 80 kg N ha^{-1} was applied five weeks after emergence. Weed control was done using the pre-emergent herbicide bullet (alachlor, MOA 15 + atrazine, MOA 5) at a dosage of 4 litres in 300 litres water ha^{-1}.

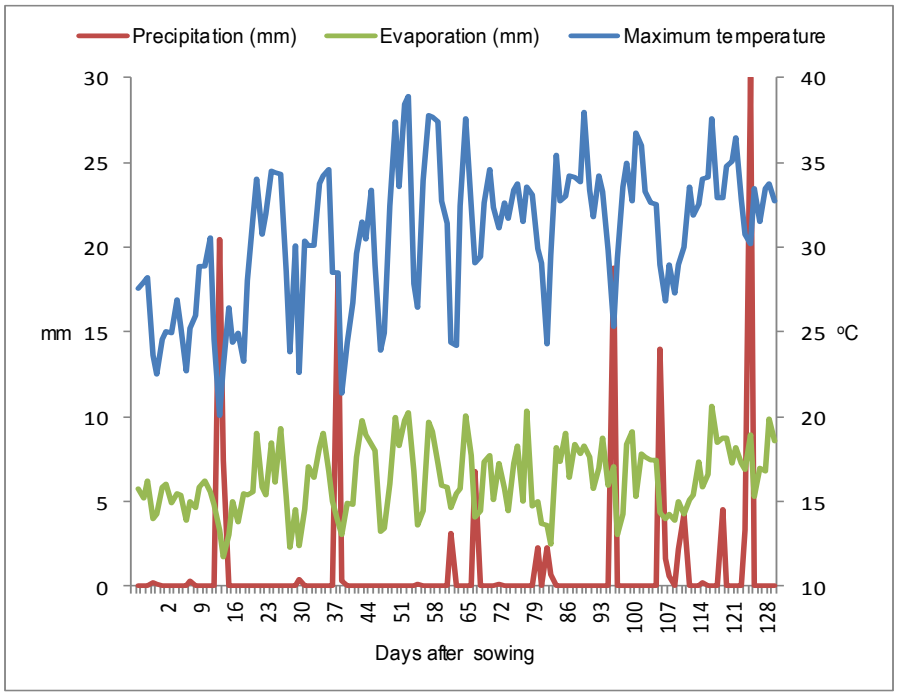

Figure 3-3-1. Daily precipitation, evaporation and maximum temperature during the dry and hot season.

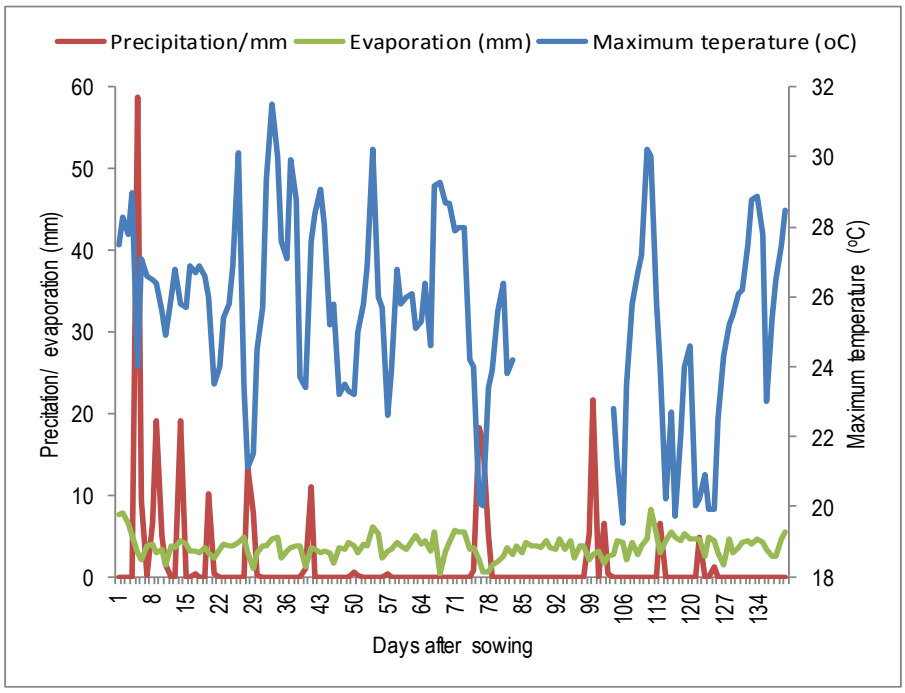

Figure 3-3-2. Daily precipitation, evaporation and temperature during the cooler and dry season (end of rainy season).

3.2.3 Experimental design and planting

The trial was randomized as a 6 × 8 alpha-lattice design with three replications per experiment. Plot sizes were two rows of 5 m long with a spacing of 0.80 m between planting rows and 0.25 m between stations within a row. Two seeds per station were sown and thinned to one plant per station at three weeks after plant emergence resulting in 21 plants row^{-1} which corresponded to a plant population density of approximately 52,500 plants ha^{-1}. Two border-rows were planted at each extreme side of the ranges and were treated similarly as the experimental plots.

3.2.4 Data collection

Recommended procedures by CIMMYT (CIMMYT, 1985; Magorokosho et al., 2008) were followed in the assessment of most of the traits and data were collected on a per plot basis. The first two plants from each end of the row were discarded as border plants in all observations. Recorded traits were days to anthesis (AD), anthesis-silking interval (ASI) as difference between days to silking and AD, plant height (PH), ear position (EPO) by dividing PH by ear height, stem lodging (SL), husk cover (HC), grain type (GT) ear aspect (EA), number of plants at harvest (NP), average number of ears $plant^{-1}$ (EPP), weight of 100 grains (W100G), average number of grains ear^{-1} (NGPE), number of grains $plant^{-1}$ (NGPP), grain weight ear^{-1} (GWPE), grain weight $plant^{-1}$ (GWPP) and grain yield (GY) in tonnes per hectare (t ha^{-1}). Average number of grains ear^{-1}, grains $plant^{-1}$ and grain yield ha^{-1} were calculated as follows:

$$NGPE = \frac{GW\ (g)}{NE} \times \frac{100\ grains}{W100G\ (g)}, \text{ [Equation 3-1]}$$

$$NGPP = \frac{GW\ (g)}{NP} \times \frac{100\ grains}{W100G\ (g)}, \text{ [Equation 3-2]}$$

$$GY\ (t\,ha^{-1}) = \frac{GW\ (g)}{1000} \times \left[\frac{100 - G.\ moisture\ (\%)}{100 - 12.5}\right] \times \frac{10}{Net\ plot\ area}, \text{ [Equation 3-3]}$$

Analysis of agronomic performance

Single environment analyses were carried out as 6 × 8 alpha-lattice design (Bänziger et al., 2000). Row-by-column analysis of variance (ANOVA) was performed for all the variables measured in Fieldbook-IMIS5 (Banziger et al., 2012) statistical software developed by CIMMYT, following the REML procedure, mixed model. Hybrid effects were considered as fixed while the

effects of the rest of the sources of variations were random. Spatial analysis was employed as recommended by Bänziger et al. (2000) as a measure to reduce experimental error in heterogeneous field trials.

3.2.5 Genetic analysis

Genetic analyses were carried out following the fixed model, Griffings' Method 4 model I, (Griffing, 1956a; b). Mean squares due to general and specific combining ability parameters were estimated and used to make inference about the type of gene action involved in the phenotypic expression of traits in which genotypic effects were found significant (Hallauer, 2007; Hallauer et al., 2010). The mathematical model for genetic analysis at single environment was as follows:

$$y_{ijkm} = \mu + Rep_k + \tau_{ij}(gca_i + sca_{ij}) + \varepsilon_{ijkm}\text{ , [Equation 3-4]}$$

where y_{ijkm} is the individual observation recorded on cross τ_{ij} in replication Rep_k of environment E_l subject to the peculiar experimental error ε_{ijkm},; μ is the trial mean in single environment or overall mean across environment; GCA_i and SCA_i are the general and specific combining ability fixed effects such that i = j;

Diallel cross and specific combining ability mean squares were tested against the pooled error mean square (MSE) but general combining ability mean squares (MSgca) were tested against specific combining ability mean squares (MSsca). Only when MSsca was not significant that MSe was used to test also MSgca (Hallauer et al., 2010). Individual parent GCA (g_i) and cross SCA (s_{ij}) effects were calculated as follows:

$$g_i = \frac{nY_{i.} - 2Y_{..}}{n(n-2)}\text{, [Equation 3-5] and}$$

$$s_{ij} = Y_{ij} - \frac{Y_{i.} + Y_{.j}}{n-2} + \frac{2Y_{..}}{(n-1)(n-2)}\text{, [Equation 3-6]}$$

where g_i is the general combining ability effect of the i^{th} parent, s_{ij} is the specific combining ability of the cross between i^{th} and j^{th} parents, n is the number of parents, $Y_{i.}$ is the total of the crosses involving parent i as female, $Y_{.j}$ is the total of the crosses involving parent j as male, and Y.. is the grand total.

Sum of squares due to GCA (SSgca) were divided by the total sum of squares (SStotal) to assess the proportion of the general combining ability effects on the total genetic variability. To judge the relative importance of general and specific combining ability effects in the observed variation among the crosses, the following ratio using sum of squares was calculated as applied by Malacarne et al. (2003).

$$\frac{SSgca}{SS(gca + sca)}, \text{ [Equation 3-7].}$$

3.3 Results

Combined Analysis of variance (Table 3-2) showed environmental effects to be statistically significant for all traits ($p < 0.001$) except for grain type ($p > 0.05$). Genotype × environment interaction effects were also significant for GY and all the yield components except number of ears plant^{-1} (EPP). Statistical models significantly explained the total variation observed for GY at all individual environments and across them ($p < 0.001$ for mean squares due to model), and the coefficients of determination (R^2) for this trait ranged from 0.581 under combined heat-drought stress (CHDS) to 0.858 under managed drought stress (MDS). Grand means for GY were 5.40, 4.35, 3.15 and 2.21 t ha^{-1} under non-stressed, heat stress alone (HS), drought stress alone (DS) and combined heat and drought stress (CHDS) environments, respectively.

3.3.1 Non-stressed conditions

Analysis of variance for agronomic performance under non-stressed environmental conditions (Table 3-3a) showed the diallel cross mean squares (MSc) for GY, W100G, NGPE, NGPP, GWPE, GWPP, PH, BHC, EA and GT to be significant at $p < 0.001$, and for AD, EPO and PA at only $p < 0.05$, while NP, EPP and ASI were not statistically significant ($p > 0.05$). The Mean squares due to general combining ability (MSgca) were significant at $p < 0.001$ for all traits and for AD at $p < 0.01$. The mean squares due to specific combining ability (MSsca) were significant for GY, W100G, NGPE and GWPP at $p < 0.001$, for NGPP, GWPE, and HC at $p <0.01$ but not significant for GT, AD, PH, EPO, PA and EA. The ratios for sum of squares (SSgca / SS(gca + sca), ranged from 0.419 for BHC to 0.766 for PH. The lowest proportion of GCA effects to the total observed genetic variability (SSgca / SStotal) was 0.170 for AD and the maximum was 0.525 for NGPE in this environment.

Table 3-2. Mean squares for grain yield and other traits of 45 diallel cross hybrids tested under four different growing conditions in 2014/15 in Mozambique.

Source of Variation	df	GY[4]	EPP	W100G	NGPE (x1000)	NGPP (x1000)	GWPE (x1000)	GWPP (x1000)	GT
ENV (E)	3	261.635***	0.427***	559.920***	138.270***	323.592***	57.188***	212.131***	0.224ns
REP(ENV)	8	1.871	0.025	14.552	5.425	6.492	0.423	0.795	0.503
Crosses (C)	44	2.165**	0.023*	39.644***	23.359***	27.308***	1.415***	1.729***	1.593***
C x E	132	1.136***	0.016ns	7.954***	6.766***	7.979***	0.744***	0.792***	0.250**
Error (e)	132	0.231	0.014	2.730	1.393	3.034	0.211	0.205	0.154
Trial mean		3.777	0.985	29.276	417.330	417.132	114.900	114.956	1.897
R^2		0.928	0.480	0.836	0.841	0.765	0.819	0.919	0.702
SE		0.392	0.098	1.349	30.473	44.978	11.866	11.694	0.321

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

Source of Variation	df	AD	ASI	PH	EPO	PA	SLODG	HC	EA
ENV (E)	3	256.931***	125.224***	69487.284***	0.032***	4.148***	16040.054***	27459.614***	44.848***
REP(ENV)	8	6.798	2.907	1316.508	0.007	2.067	664.804	230.896	0.726
Crosses (C)	44	15.036***	3.311*	1152.574***	0.007***	0.716*	232.504*	457.546***	0.851**
C x E	132	3.417ns	2.344**	211.762ns	0.001ns	0.445ns	158.273ns	205.200***	0.431*
Error (e)	132	3.179	1.605	215.581	0.001	0.355	121.349	53.569	0.309
Trial mean		50.144	1.888	171.440	0.499	2.375	12.210	13.860	2.766
R^2		0.634	0.604	0.797	0.585	0.540	0.641	0.871	0.678
SE		1.456	1.034	11.988	0.029	0.487	8.994	5.976	0.454

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3a. Fixed model ANOVA for grain yield and other traits of diallel cross hybrids evaluated under non-stressed condition at Chókwè Research Station in 2015.

Source of Variation	Df	GY	NP	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT
REP	2	0.405	2.903	0.030	31.733	10980.438	6685.438	214.903	149.236	0.456
Crosses (C)	44	2.050***	29.872^{ns}	0.016	19.153***	13429.256***	14985.852***	1145.022***	1445.700***	0.461***
GCA	9	5.665***	-	-	63.336***	45251.870***	45731.940***	2459.810***	3991.200***	1.314***
SCA	35	1.121***	-	-	7.792***	5246.300***	7079.710**	806.940**	791.140**	0.2401^{ns}
Error (e)	88	0.315	24.368	0.015	3.944	1850.886	3768.115	394.573	217.215	0.172
Trial mean		5.400	33.836	1.016	30.063	449.611	454.862	135.807	159.522	1.929
R^2		0.767	0.383	0.370	0.723	0.790	0.670	0.594	0.770	0.586
SE		0.458	4.031	0.100	1.622	35.127	50.121	16.219	12.034	0.338
LSD		0.910	8.010	0.199	3.223	69.808	99.604	32.231	23.914	0.672
SSgca / SS(gca+sca)		0.565	-	-	0.676	0.690	0.624	0.439	0.565	0.585
SSgca / SStotal		0.429	-	-	0.455	0.525	0.410	0.259	0.433	0.328

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3a. (continued)

Source of Variation	df	AD	ASI	PH	EPO	PA	SLODG	HC	EA
REP	2	5.067	1.422	31.359	0.007	1.549	.	4.950	1.453
Crosses (C)	44	10.699*	0.413^{ns}	488.705***	0.002*	0.705*	.	2.495***	0.767***
GCA	9	19.878**	-	1830.680***	0.005***	1.790***	.	5.086***	2.143***
SCA	35	6.957^{ns}	-	143.620^{ns}	0.001^{ns}	0.392^{ns}	.	1.813**	0.424^{ns}
Error (e)	88	7.059	0.549	158.965	0.001	0.432	.	0.801	0.288
Trial mean		48.711	1.402	192.276	0.504	2.237	.	3.823	2.112
R^2		0.410	0.311	0.607	0.487	0.536	.	0.634	0.594
SE		2.169	0.605	10.295	0.027	0.536	.	0.731	0.439
LSD		4.311	1.203	20.458	0.055	1.070	.	1.452	0.871
SSgca / SS(gca+sca)		0.424	-	0.766	0.545	0.540	.	0.419	0.565
SSgca / SStotal		0.170	-	0.463	0.228	0.251	.	0.243	0.312

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

3.3.2 Managed drought stress conditions

Under managed drought condition (Table 3-3b), mean squares for the crosses were significant for all traits except for EPP and ASI (non-significant). For most of the traits, significance was at $p < 0.001$ but for EPO and PH was at $p < 0.05$. Genetic analyses at this environment resulted in statistically significant MSgca at $p < 0.001$ for GY, W100G, NGPE, NGPE, GWPE and AD, at $p < 0.01$ for PH, and at $p < 0.05$ for EPO. The MSsca were statistically significant ($p < 0.001$) for GY and all yield components, except EPP in which hybrid mean square was not significant. Calculated combining ability effect ratios ranged from a minimum of 0.121 for number of plants harvested to a maximum of 0.654 for AD. Low proportions of SSgca to total sum of squares were obtained for most of the traits under moderate drought stress and they ranged from a minimum of 0.073 for NP to a maximum of 0.495 for W100G.

3.3.3 Heat stress conditions

Under heat stress conditions (Table 3-3c), highly significant ($p < 0.001$) mean squares were observed for the majority of the traits except for EPP and PH ($p < 0.05$). For NP, SLODG and EA mean squares were not statistically significant ($p > 0.05$). Analysis of variance for genetic components resulted in significant MSgca at 0.001 for most of the traits except for EPP and PA ($p <0.05$). Half of the traits (GY, W100G, NGPE, NGPP, GWPE, GWPP and HC) had significant MSsca at $p < 0.001$. For GT and PA, MSsca were significant at $p < 0.01$ and $P < 0.05$, respectively. Mean squares due to SCA for EPP, AD, ASI, PH and EPO were not significant ($p > 0.05$). Combining ability effect ratios ranged from 0.288 for GY to 0.789 for EPO. Contribution of GCA effects to total sums of squares ranged from 0.138 for EPP to 0.532 for EPO.

3.3.4 Combined heat and drought stress conditions

For the combined heat-drought stress, W100G was not recorded. Therefore, it was not possible to calculate NGPE and NGPP. Analysis of variance for the measured traits (Table 3-3d) resulted in statistically significant hybrid mean squares for GWPE, GWPP and PA ($p < 0.05$), for GY, AD, and EA ($p < 0.01$), and for PH, EPO, BHC and GT ($p < 0.001$), but not for EPP and SL. Genetic analyses showed that MSgca were significant for all measured traits except ASI ($p > 0.05$), while MSsca were significant only for GT and HC ($p < 0.001$), and plant heights at $p < 0.05$. Significance of MSgca were very high ($p < 0.001$) for GY, GWPP,

Table 3-3b. Fixed model ANOVA for grain yield and other traits of diallel cross hybrids evaluated under drought conditions alone at Chókwè Research Station in 2015.

Source of Variation	df	GY	NP	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT
REP	2	0.111	14.541	0.007	7.315	3252.467	8005.089	450.489	1080.467	.
Crosses (C)	44	1.029***	45.469***	0.028*	19.215***	11045.718***	12447.885***	1275.167***	1305.385***	.
GCA	9	1.726***	26.789***	-	57.965***	32725.750***	27322.380***	3820.220***	2941.510***	.
SCA	35	0.850***	50.273***	-	9.250***	5470.850***	8623.010***	620.720***	884.670***	.
Error (e)	88	0.086	14.526	0.018	2.200	1514.777	3328.793	161.815	297.876	.
Trial mean		3.153	30.385	1.049	30.796	417.089	435.0222	128.333	133.644	.
R^2		0.858	0.614	0.660	0.816	0.787	0.658	0.800	0.695	.
SE		0.239	3.112	0.111	1.211	31.778	47.108	10.386	14.092	.
LSD		0.475	6.184	0.220	2.407	63.152	93.618	20.641	28.005	.
SSgca / SS(gca+sca)		0.343	0.121	-	0.617	0.606	0.450	0.613	0.461	.
SSgca / SStotal		0.310	0.073	-	0.495	0.471	0.287	0.483	0.309	.

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%)

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3b (continued)

Source of Variation	df	AD	ASI	PH	EPO	PA	SLODG	HC	EA
REP	2	2.867	1.156	57.655	0.006	.	756.071	.	.
Crosses (C)	44	4.233***	2.303^{ns}	405.683*	0.001	.	305.804^{ns}	.	.
GCA	9	13.530***	-	918.459**	0.003*	.	-	.	.
SCA	35	1.843^{ns}	-	273.827^{ns}	0.001^{ns}	.	-	.	.
Error (e)	88	1.397	2.277	297.8805	0.002	.	0.002	.	.
Trial mean		50.644	3.333	139.147	0.477	.	0.477	.	.
R^2		0.610	0.341	0.407	0.282	.	0.282	.	.
SE		0.965	1.232	14.092	0.038	.	0.038	.	.
LSD		1.918	2.448	28.005	0.076	.	0.076	.	.
SSgca / SS(gca+sca)		0.654	-	0.463	0.368	.	-	.	.
SSgca / SStotal		0.387	-	0.187	0.179	.	-	.	.

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3c. Fixed model ANOVA for grain yield and other traits of diallel cross hybrids evaluated under heat conditions alone at Chókwè Research Station in 2014.

Source of Variation	df	GY	NP	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT
REP	2	4.644	83.585	0.004	4.609	2041.732	4784.273	439.252	772.452	0.891
Crosses (C)	44	2.151***	9.714^{ns}	0.013*	17.183***	12396.465***	15810.898***	869.867***	1103.245***	0.618***
GCA	9	3.032***	-	0.019*	44.961***	29824.830***	36819.400***	1486.270***	1774.640***	2.030***
SCA	35	1.924***	-	0.008^{ns}	9.818***	7961.580***	10485.150***	711.360***	930.600***	0.255**
Error (e)	88	0.362	8.487	0.009	2.039	806.466	1994.745	56.509	155.596	0.126
Trial mean		4.349	37.748	0.934	26.951	385.052	361.097	103.370	97.081	1.852
R^2		0.765	0.443	0.360	0.812	0.887	0.803	0.887	0.785	0.724
SE		0.492	2.379	0.077	1.166	23.187	36.467	6.138	10.185	0.289
LSD		0.977	4.727	0.153	2.317	46.080	72.470	12.198	20.240	0.575
SSgca / SS(gca+sca)		0.288	-	-	0.541	0.491	0.475	0.349	0.329	0.672
SSgca / SStotal		0.201	-	-	0.429	0.433	0.377	0.303	0.250	0.456

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%)

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3c. (continued)

Source of Variation	df	AD	ASI	PH	EPO	PA	SLODG	HC	EA
REP	2	11.341	8.674	2959.961	0.005	.	933.946	527.497	0.185
Crosses (C)	44	5.373***	6.321***	483.304*	0.004***	.	366.022^{ns}	717.032***	0.581^{ns}
GCA	9	20.511***	21.980***	1269.910***	0.017***	.	-	2061.590***	-
SCA	35	1.480^{ns}	2.294^{ns}	281.040^{ns}	0.001^{ns}	.	-	371.290***	-
Error (e)	88	1.432	2.742	313.96983	0.001	.	264.280	112.134	0.448
Trial mean		51.830	1.415	176.278	0.512	.	24.723	30.190	3.230
R^2		0.673	0.550	0.496	0.713	.	0.436	0.768	0.396
SE		0.977	1.352	14.468	0.025	.	13.274	8.646	0.547
LSD		1.941	2.687	28.751	0.050	.	26.378	17.182	1.087
SSgca / SS(gca+sca)		0.781	0.711	0.537	0.789	.	-	0.588	-
SSgca / SStotal		0.479	0.369	0.209	0.534	.	-	0.437	-

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3d. Fixed model ANOVA for grain yield and other traits of diallel cross hybrids evaluated under combined heat and drought condition at Chókwè Research Station in 2014.

Source of Variation	df	GY	NP	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT
REP	2	2.335	157.163	0.056	.	.	.	585.867	1179.622	0.163
Crosses (C)	44	0.447**	41.342*	0.019^{ns}	.	.	.	358.370*	251.688*	1.014***
GCA	9	1.376***	71.935**	-	.	.	.	511.085*	528.002***	3.138***
SCA	35	0.208^{ns}	33.475^{ns}	-	.	.	.	319.100^{ns}	180.636^{ns}	0.468***
Error (e)	88	0.161	23.951	0.015	.	.	.	231.942	149.766	0.166
Trial mean		2.207	40.148	0.941	.	.	.	92.089	69.578	1.909
R^2		0.581	0.503	0.412	.	.	.	0.454	0.505	0.754
SE		0.328	3.996	0.101	.	.	.	12.435	9.992	0.333
LSD		0.652	7.941	0.200	.	.	.	24.712	19.857	0.662
SSgca / SS(gca+sca)		0.614	0.356	-	.	.	.	0.292	0.429	0.633
SSgca / SStotal		0.228	0.153	-	.	.	.	0.123	0.179	0.474

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover.

Table 3-3d (continued)

Source of Variation	df	AD	ASI	PH	EPO	PA	SLODG	HC	EA
REP	2	7.919	0.474	2217.059	0.008	2.585	37.064	160.241	0.541
Crosses (C)	44	6.080**	1.307*	410.166***	0.003***	0.496*	58.081*	153.283***	0.358**
GCA	9	18.344***	1.557^{ns}	1418.710***	0.010***	0.781**	91.752*	292.285***	0.746***
SCA	35	2.927^{ns}	1.243^{ns}	150.830*	0.001*	0.423^{ns}	30.207^{ns}	117.540***	0.259^{ns}
Error (e)	88	2.828	0.815	91.506	0.001	0.295	38.209	46.573	0.188
Trial mean		49.393	1.393	178.058	0.504	2.493	7.127	7.418	2.952
R^2		0.532	0.449	0.736	0.693	0.509	0.368	0.633	0.504
SE		1.373	0.737	7.811	0.022	0.444	5.047	5.572	0.354
LSD		2.729	1.465	15.522	0.044	0.882	10.030	11.073	0.704
SSgca / SS(gca+sca)		0.617	0.244	0.707	0.661	0.322	0.439	0.390	0.426
SSgca / SStotal		0.310	0.108	0.418	0.406	0.133	0.155	0.236	0.201

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant-1; **W100G** = weight of 100 grains; **NGPE** = number of grains ear-1; **NGPP** = number of grains plant-1; **GWPE** = grain weight ear-1; **GWPP** = grain weight plant-1; **GT** = grain type (texture) ; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EPO** = ear position; **PA** = plant aspect; **EA** = ear aspect; **SLODG** = stem lodging; **HC** = husk cover

GT, AD, PH, EPO, HC and EA. For NP and PA, MSgca were significant at $p < 0.01$, while for GWPE and SLODG were at only $p < 0.05$. Ratios of sums of squares due to GCA over SS(gca+sca) varied from 0.259 for EA to 0.950 for EPO and SSgca / SStotal ratios varied from 0.123 for GWPE to 0.950 for PH.

3.4 Discussion

Due to smaller number of parents that succeeded to be crossed in this study, only a fixed model was followed to carry out genetic analyses (Griffing 1959a,b). Although the most important output of this model are the individual parents GCA and crosses SCA effects estimates, it is possible to use the combining ability information to make inference about gene action governing the targeted traits, since GCA effects are mainly due to additive gene action while SCA effects are more influenced by non-additive (intra and inter allelic interaction) type of gene action (Hallauer, 2007). Accordingly, the (SSgca / SStotal) ratio can be compared to narrow sence heritability. In this study, the results are relevant to tropical lowland maize germplasm, since the experiments were conducted in the lowland areas. The ten parents were randomly selected and they were developed under tropical environments from ten different tropical maize populations.

The highly significant environmental mean squares observed for all traits indicate that the experimental growing conditions were very different (Abdel-Moneam et al., 2014; Allinne et al., 2009; Aly et al., 2011; Bello and Olaoye, 2009). Significant environmental effects for all traits combined with genotype × environment interactions for the main trait (GY) and its components suggest that results should be treated separately for each environment (Clewer and Scarisbrick, 2001; Gomez and Gomez, 1984; Montgomery, 2005; Pimentel-Gomes, 2009).

3.4.1 Environmental classification

The grand mean for grain yield for the fully-irrigated experiment that flowered from 11th to 20th of October 2014 was 4.35 t ha^{-1}, and it was 89% of the reference experiment, ("non-stressed" which had a grand mean yield of 5.40 t ha^{-1}), whose flowering was from 27th of March to 4th of April 2015. The observed reduction of 19% in yield could be attributed to another cause other than drought since soil moisture was adequate throughout the growing period until physiological maturity. It was observed from the temperature graphs that there were a number of days when the maximum temperatures were above 35^{o}C during and after flowering hotter October period of the 2014 season. The optimum threshold temperature for

maize was reported to be around 35ºC (Luo, 2011; Sánchez et al., 2014), and this shows that the crop experienced unfavourable temperatures for some days during pollen shedding, silking and cob formation. Lobell et al. (2011) observed that an increase in one degree Celsius above the optimal threshold limit can cause a yield reduction of up to 17% day^{-1}. It is, therefore, clear that the experiment experienced heat stress alone (HS) on some of the days during the reproductive period resulting in less average yields (4.5 t ha^{-1}) compared to the non-stressed yield of April 2015 (5.4 t ha^{-1}).

The managed drought condition imposed on the experiment grown during the relatively cooler period (end of rainy season) was enough to cause yield reduction of about 41% compared to non-stressed condition. None of the days during the reproductive period registered temperatures above 35ºC (Figure 3-2), therefore, it was very unlikely that the crop experienced heat stress. Compared with the HS experiment, yield reduction was about 27% due to drought alone (3.15 t ha^{-1}). The managed drought stress experiment was established exactly on the same date and treated similarly as the non-stressed environment except for the water-regime. Therefore, the 41% yield penalty compared to the non-stressed environment (5.4 t ha^{-1}) could probably be explained by drought stress (DS) during the reproductive period. The DS seemed to have a more negative effect compared to the IHS.

The reduced yield penalty due to HS (-1.55 t ha^{-1}) as compared to DS (-2.25 t ha^{-1}) can be explained by the fact that the maize plant, as a C4 plant species, can acclimatise (self-cooling) when water is not a limiting factor (Bird et al., 1977; Cicchino et al., 2010; Dwyer et al., 2007; Rattalino Edreira and Otegui, 2012; Sage and Kubien, 2007; Sánchez et al., 2014; Yamori et al., 2014). However, it cannot be expected that the acclimatisation results in zero yield penalty when compared to “optimum” temperature environments. Bänziger et al. (2000) and Betrán et al. (2003b) classified experiments with yield reduction of about 50% as moderate drought stress. To be classified as severe drought stress environment, grain yield must be reduced to about 15 – 20% of the yield under well-watered environment at the same site and same season (Bänziger et al., 2000; Bolaños and Edmeades, 1996). Therefore, the drought stress experiment under discussion falls on the moderate drought stress side.

When the crop experienced drought and high temperatures at the same time (managed drought experiment during the hot and dry season) yields averaged 2.21 t ha^{-1}, which correspond to a yield reduction of 59% compared to the non-stressed environment experiment. This was because, under water limited environments, the acclimatisation mechanism mentioned above was impaired. Since HS effect on yield was mild and the DS was moderate, the combination of the two was classified as moderate heat-drought stress (MHDS) in this study. In fact, the 59% yield reduction falls within the range of moderate

stress as mentioned above. Hence, these results must be considered as moderate levels of heat, drought and combined heat-drought stresses.

3.4.2 Combining ability and gene action for grain yield and components of yield

Grain yield (GY) as defined by its components is: $GY = NP\ ha^{-1} \times EPP \times NGPE \times GW$ (Bänziger et al., 2000), where NP is the plant population at harvesting, EPP is the average number of ears plant^{-1}, NGPE is the average numaber of grains ear^{-1} and GW is the average weight of each grain. Therefore, the most important yield components in this case are the NP, EPP, NGPE and W100G (weight of 100 grains). However, average grain weight and NGPE translate to GWPE, and with number of EPP result in GWPP. Thus, NP, EPP, NGPE, NGPP, GWPE and GWPP are important yield components, thus, they must be considered in the present study.

Grain Yield

The highly significant ($p < 0.001$) genetic variation detected under non-stressed experimental condition (Table 3-3a) for GY was due to the significant contribution of both general and specific combining ability effects (MSgca and MSscas, respectively) implying that both additive and non-additive gene action played an important role in the phenotypic expression of the main trait (Acquaah, 2007; Falconer and Mackay, 1996; Hallauer, 2007; Hallauer et al., 2010). The SSgca / SS(gca + sca) ratio of 0.565, closer to half, indicated that additive and non-additive gene actions contributed with almost similar weight in the total genetic effects sum of squares for GY under fully-irrigated and cooler environment. This explains the estimated proportion of GCA effects over the total sums of squares of 0.429 which is almost midway. The combined involvement of both additive and non-additive gene action for GY in maize under non-stressed conditions has been recognised since long back (Eberhart and Hallauer, 1968; Gamble, 1962a; b; Machida et al., 2010; Melchinger et al., 1986; Moreno-Gonzalez and Dudley, 1981; Stuber and Moll, 1971) and it was a common finding in several later genetic studies (Abdel-Moneam et al., 2014; Adebayo et al., 2014; Badu-Apraku, 2007; Chen et al., 2012; Mhike et al., 2011; Oliveira et al., 2011; Passos et al., 2010; Souza et al., 2009; Teklewold and Becker, 2005; Troyer and Wellin, 2009; Vivek et al., 2009; Zare et al., 2011; Zare-kohan and Heidari, 2012; Zeinab and Helal, 2014).

Under drought alone and heat alone, both GCA and SCA had highly significant effects on the hybrid variation for GY but the two GCA ratios (0.343 under DS and 0.288 under HS) were comparatively lower than under non-stressed condition, suggesting that importance of

non-additive gene action increased more than the additive (Hallauer, 2007) under these moderate individual stress conditions. The low ratio of GCA over the two combining ability ratios (0.343 under DS and 0.288 under HS) indicate the predominance of non-additive over additive gene action. Consequently, GCA effects over total effects on GY were also lower (0.310 under IDS and 0.201 under IHS), meaning that breeding progress would be slower when selections are done under individual stress environments.

The significance of the general combining ability effects for GY under drought stress alone agrees with several previous studies under similar drought stress category (moderate) that include Betrán et al. (2003b), Derera et al. (2008) and Oyekunle and Badu-Apraku (2014). A study by Adebayo et al. (2014) found significant ($p < 0.05$) female GCA effects and not male GCA in North Caroline Design II (NCDII) crosses evaluated under drought. Under heat stress alone, the results are in full agreement with findings by Akbar et al. (2008) on genetic studies for heat stress tolerance where both GCA and SCA effects were significant and only the non-additive related component of variance was important for all traits, including GY, in that study.

Contrary to the individual stresses, under combined stress conditions genetic properties were different. The MSgca for GY was highly significant ($p < 0.001$) but MSsca was not significant ($p = 0.16970$). The results suggest that, when heat and drought stresses are combined in the same treatment, additive gene effects for GY become more important than non-additive effects. In line with the present findings, Derera et al. (2008) and Makumbi et al. (2011) also found predominance of additive over non-additive gene action using tropical maize germplasm under drought stress environments. Badu-Apraku (2007) reported that the inheritance of maize GY was dominated by additive genetic variance when the crop was under striga (*Striga hermonthica*) stress. The present results confirmed that the importance of either additive or non-additive gene action for GY is dependent on environmental conditions and the genetic background of the materials used (Hallauer, 2007). Relatively high GCA over the total combining ability ratio (0.614) under combined heat and drought stress conditions compared to individual stresses and non-stressed conditions reinforce that additive gene action was more important under the combined stress.

The GCA over the total sum of squares ratios under the three moderately stressed experimental conditions in this study suggest that progress would be relatively slow when selections are carried out using only grain yield, for combined heat and drought stress tolerance. This solicits for the incorporation of other traits and finding out whether the progress can speed up. However, further research that will include severe stresses is needed.

Grain components of yield

For the measured components of yield, NGPE, NGPP, W100G, GWPE and GWPP, significant MSgca and MSsca were observed indicating important roles played by both additive and non-additive gene action for the genotypic differences observed (Acquaah, 2007; Hallauer, 2007; Hallauer et al., 2010) under non-stressed, heat and drought stress conditions. Based on the obtained general combining ability ratios in different experimental conditions, it is observed that additive gene action was predominant under combined stress conditions, and non-additive was predominant under separate moderate stresses.

Grain Type/ texture

Most genetic studies do not include grain type or texture (GT), most probably because it is not a yield component. However, GT is associated with grain size and weight, and is one of the most important characteristics used by farmers to choose a variety in Mozambique (Denic et al., 2008). Furthermore, Vasal et al. (1993) observed that crosses among dents and dent × flints yielded higher than crosses among flints. In the current study, grain type was not evaluated under drought alone but under non-stressed, heat alone and combined heat and drought stress conditions. Mean squares for the crosses were highly significant ($p < 0.001$). Both MSgca and MSsca were significant under the two stressed environments (heat alone and combined heat and drought) and only the MSgca was significant under non-stressed conditions. However, the resulting Bakers' ratios suggest importance of both additive and non-additive gene actions in controlling grain hardness under heat alone and combined stress conditions, and also under the non-stressed experimental environment.

Average number of ears plant^{-1}

Ears per plant (EPP) were significant only under isolated heat stress and the genetic effects were explained by additive gene action, with MSgca significant at $p < 0.05$, while MSsca was non-significant ($p = 0.7019$). The number of EPP has been associated with tolerance to drought in many studies (Araus and Sanchez, 2012; Badu-Apraku, 2007; Badu-Apraku et al., 2012; Betrán et al., 2003c; Meseka et al., 2011; Mhike et al., 2012), since stress leads to barrenness when maize plants are stressed in the interval from just before tassel emergence to the beginning of grain fill (Edmeades et al., 1997). The observed non significance of genetic effects for EPP under the two drought environments and non-stressed conditions in this study is in agreement with Bänziger et al. (2000) who stated that EPP was affected mainly by severe drought stress, but this was not the case in this study. Therefore, no

comparisons of the type of gene action controlling EPP under heat, drought and combined heat and drought stress conditions could be made.

3.4.3 Combining ability and gene action for other traits

Anthesis and anthesis-silking interval

Significant MSgca and non-significant MSsca at the four individual environments for number of days to anthesis (AD) is an indication that only additive gene action is important on the inheritance of AD. Similar findings were obtained by Derera et al. (2008) and Adebayo et al. (2014). In the present study, the ratios of GCA effects over total sum of squares for combining abilities were high under stressed conditions, ranging from 0.633 under combined stress to 0.781 under isolated heat, which reinforces the conclusion that additive gene action is more important than non-additive in controlling AD in maize, regardless of the environmental conditions under which the maize is grown. Consequently, narrow sense heritability estimates were also very high, ranging from 0.739 to 0.980. In contrast, a study by Alam et al. (2008) reported statistically significant variation due to both GCA and SCA effects for number of days to flowering in maize. However, although SCA effects were significant, additive gene action was still predominant over non-additive gene action. For ASI, only MSgca was significant under isolated heat. This confirms that flowering traits in these maize lines were dominantly controlled by additive gene action.

Plant height, ear position, plant aspect, ear aspect and stem lodging

Similar to AD, significant genotypic variation for both plant height (PH) and ear position (EPO) were more explained by GCA effects irrespective of the environment as only MSgca was significant under all environmental conditions, except in the combined stress environment where MSsca was also significant at $p < 0.05$. Values of GCA ratios for the two traits were generally high except under IDS (0.463 for PH and 0.368 for EPO). However, there have been no consistent conclusions on the kind of gene action controlling PH in maize. Some studies reported a large proportion of SCA than GCA effects (Akbar et al., 2008; Alam et al., 2008), while others attributed the genetic control to additive gene action (Bhatnagar et al., 2004; Gonzalez et al., 1997; Malacarne and San Vicente, 2003; Mhike et al., 2011), similar to results of this study.

Plant aspect (PA) is highly correlated with GY under stressed conditions (Badu-Apraku, 2007). Studies on gene action controlling this trait are scarce. In the present study PA was evaluated under non-stressed and under combined stress conditions. Significance of MSgca

alone suggests importance of only additive gene action under unstressed conditions and both additive and non-additive gene action under combined stress. Calculated ratios of GCA effects over total sum of squares for combining ability (0.540 and 0.322 under non-stressed and stressed conditions, respectively) also revealed a tendency of additive gene action to be predominant over non-additive under non-stressed environments while non-additive gene action could be also exploited under combined stress conditions. A similar trend was observed for ear aspect (EA). These results are in agreement with the other genetic studies for EA reported by Adebayo et al. (2014), Derera et al. (2008) and Oyekunle and Badu-Apraku (2014).

Husk cover of the ears

Husk cover (HC) is another trait that has received little attention from scientist regarding its genetic properties under stressed environment. In this study, results suggest that additive and non-additive gene actions are equally important regardless of the environment as both MSgca and MSsca were statistically significant ($p < 0.01$) at a particular environment. Ratios of GCA effects over total sum of squares of combining ability effects were almost similar under all the environments indicating that the two types of gene action, additive and non-additive, controlled the quality of the ears under both stressed and non-stressed environments. Husk cover characteristic is very easy and quick to assess, therefore, combined with other secondary traits, it can contribute to faster progress.

3.5 Conclusion

The managed drought and the daily maximum temperatures that occurred during the experimental growing periods of this research study were only adverse enough to cause moderate heat and moderate drought stresses. The stressed environments were significantly different from the unstressed environment and the significant genotype × environment interaction revealed that the level of performance of the hybrids depended on growing conditions.

General and specific combining ability effects were significant for grain yield and all yield components, except number of ears plant^{-1} under the four individual environments indicating importance of both additive and non-additive gene action in controlling these traits. However, additive gene action was generally predominant in most of the cases and its predominance increased on moving from the individual stresses to combined heat-drought stress conditions.

For the other evaluated traits, additive gene action was clearly predominant over non-additive regardless of the stress category, except for husk cover in which the two types of gene action were equally important.

The practical implication of the results is that improvement of tropical maize for combined heat-drought stress tolerance is possible and it can be faster when selections is conducted under combined heat-drought stress conditions than under heat and/or drought separately.

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4. CHAPTER 4. Heterotic orientation of thirty maize inbred lines under full-irrigation versus combined heat-drought stress conditions

Abstract

Heterotic group classification is a common procedure in maize (*Zea mays* L.) to improve breeding efficiency by facilitating germplasm management and organization. The objective of this study was to determine the heterotic orientation of thirty selected maize inbred lines using three drought-tolerant (CML312, CML444 and CML 445) and one high yield potential (N3) males as testers. A line × tester mating design was used to generate 120 testcrosses. The crosses were evaluated at Chókwè Research Station under full-irrigation and random drought stress conditions during the main cropping season 2014/15. Data on grain yield were analysed using line × tester procedure. Heterotic specific and general combining ability (HSGCA) grouping method was used to assign the thirty female lines to the four tester groups. Both general combining ability (GCA) due to lines and testers, and specific combining ability (SCA) due to line × tester were significant ($p < 0.05$) under full-irrigation and highly significant ($p < 0.01$) under stressed conditions. The proportion of SCA effects was bigger than the GCA effects under full-irrigation and both were equal under stressed environment, indicating that SCA effects were more important than GCA effects under non-stressed conditions with the importance of GCA increasing under stressed conditions. Contribution of lines (female parents) to the total GCA was bigger than that of testers at both experimental conditions. The four males (testers) were successfully associated with a group of female lines, but 67% of the lines changed their heterotic orientation when experimental conditions changed. Female lines 7, 25, 26, 28, 29, 33, 34, 35, 36 and 39 were the best general combiners across the two environments, therefore, they have potential to be used for hybrid formation. Lines 7, 25, 26, 29 and 35 generated tolerant hybrids to combined heat and drought stress, and thus, they were recommended for future use.

4.1 Introduction

Maize is the most important food crop grown in Mozambique, judged by the percentage of land-holdings (69%) growing it and the area (44%) occupied by the crop nationwide (INE, 2011). It is also a strategic crop for food security and social prestige (Fato, 2010). Apart from breeding for multiple-stress tolerance, the Mozambique National Programme dedicated special attention to the development of hybrid varieties as one of the strategies in improving the low maize yields across the country.

Heterotic group classification of inbred lines is one of the main activities of breeding programmes and it is helpful in raising the breeding efficiency by facilitating germplasm management, organization and predicting the performance of maize hybrids (Carena, 2009; Fan et al., 2009; Malacarne et al., 2003; Zhang et al., 2002). This is because it is not possible to sufficiently correlate the actual performance of the inbred lines with the performance of their hybrid progenies for important agronomic characters, especially grain yield (Hallauer, 2007; Malacarne and San Vicente, 2003). Besides, the concept of heterotic patterns helps breeders to choose parents of crosses for line development, as well as testers to evaluate combining ability of newly developed inbreds (Reif et al., 2005).

A heterotic group was defined by Melchinger and Gumber (1998) as “a group of related or unrelated genotypes, from the same or different population, that display similar combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm group” (Reif et al., 2005). Carena (2008) simplified the concept by stating that heterotic patterns are crosses between known genotypes that express high levels of heterosis. Different methods including molecular techniques have been used to separate germplasm into heterotic groups, but the evaluation of single diallel or line × tester crosses remains the most common method (Hallauer, 2007). According to Hallauer (2007), line × tester approach is recommended when the number of new inbred lines to be classified is high and when known testers are available.

In tropical and sub-tropical maize, it is a common practice to separate germplasm into two divergent heterotic groups, referred to as heterotic group A (HGA) and heterotic group B (HGB) (Vasal et al., 1999). Germplasm from HGA exhibit better heterosis when crossed with germplasm from HGB and vice-versa, but within the same heterotic group heterosis is lower. Therefore, testers to be used to separate new germplasm in different heterotic groups must show high heterosis when crossed together, i.e. they form a good heterotic pattern (Reif et al., 2005). According to Vasal et al. (1999), testers can be genetically divergent synthetics, inbred lines or F_1 single crosses from the same heterotic group (A×A and B×B). The choice

depends on the ultimate objective and availability of the desired tester. The use of synthetics is common in population improvement while F1 single crosses are used when the breeder intends to use superior test crosses as final three-way hybrid varieties. When the objective is to classify newly developed inbred lines, use of known inbred testers is recommended (Vasal et al., 1999).

In Mozambique, the newly developed and introduced inbred lines were not characterised and no heterotic patterns were clearly identified under local growing conditions. Therefore, this study was designed to assess combining ability and heterotic orientation of the promising inbred lines available in the country towards known testers in the region.

4.2 Materials and Methods

4.2.1 Germplasm

Thirty inbred lines were used as female parents and crossed to four male testers using the line × tester mating design at Chókwè Research Station during the dry-season of 2014. Half of the female lines were developed in Mozambique (Table 4-1). The testers included two well-known drought tolerant tropical maize testers (CML312 = tester "A" and CML444 = tester "B") in Southern Africa Region, CML445 a parent to drought tolerant three-way cross hybrid released in Mozambique in 2011 classified as "AB" line by CIMMYT and N3 a parent of the very well-known high-yielding single-cross hybrid in Africa (SR52) developed by the Zimbabwean national programme. The N3 was designated as drought susceptible tester.

The resulting 120 testcross hybrids were evaluated together with six single crosses resulting from all possible combinations of the four testers (CML312/CML444, CML312/CML445, CML312/N3, CML444/CML445, CML444/N3 and CML445/N3) and CML442/CML539 = A × A and CML395/CML444 = B × B. In total 128 entries, all single-crosses were evaluated for yield performance.

4.2.2 Evaluation

Two experiments were grown at Chókwè Research Station during the main cropping season of 2014/15. One of the experiments was under full irrigation until physiological maturity (non-stressed treatment) and the second was under stress treatment (irrigation stopped a five days after top-dress fertilisation, i.e., 40 days after emergence). The weather information collected during the period of the experiments is summarized in the Figure 4-1. The

experiments were randomised in an 8 × 16 alpha-lattice with 2 replications per experiment using Fieldbook-IMS5 statistical software developed by CIMMYT (Bänziger et al., 2012). Field layout was arranged as 8 rows × 16 columns within replication.

Table 4-1. Female (TCL1 – TCL42) and male (tester) lines crossed to generate testcross hybrids evaluated under non-stressed and stressed conditions at Chokwe during the main cropping season 2014/15.

Nursery-Entry	Pedigree/Code	Origin
TCL1	ZM421-2-1-2-1-2-2-1-B*2-B (1)	IIAM-Mozambique
TCL2	ZM421-18-8-1-3-1-5-1-1-B (20)	IIAM-Mozambique
TCL3	ZM421-40-1-2-2-3-4-1-B (24)	IIAM-Mozambique
TCL4	ZM421-72-1-1-3-3-1-1-B (26)	IIAM-Mozambique
TCL6	ZM521-8-4-2-3-1-2-1-B (44)	IIAM-Mozambique
TCL7	ZM521-13-3-2-3-1-1-B*2-B (31)	IIAM-Mozambique
TCL9	ZM521-29-2-1-1-1-2-5-B (35)	IIAM-Mozambique
TCL10	ZM521-38-2-3-1-1-3-1-1-B (38)	IIAM-Mozambique
TCL11	ZM521-40-1-3-1-1-5-B*2-B (41)	IIAM-Mozambique
TCL12	ZM521-42-2-1-2-1-2-1-B (43)	IIAM-Mozambique
TCL14	ZM621-19-4-2-1-1-1-2-1-B (46)	IIAM-Mozambique
TCL18	INTBC1F2FS-19-2-2-1-1-1-1-1-B (50)	IIAM-Mozambique
TCL21	TSEGRIM-3-1-5-2-1-1-3-1-B (68)	IIAM-Mozambique
TCL23	CHINACAFS-80-2-1-3-1-B	IIAM-Mozambique
TCL24	LaPostaSeqC7-F18-3-2-1-1-B*9 (106)	CIMMYT-Mexico
TCL25	DTPYC9-F46-1-2-1-1-B (107)	CIMMYT-Mexico
TCL26	DTPYC9-F46-1-2-1-2-B (108)	CIMMYT-Mexico
TCL27	DMR15B (69)	IIAM-Mozambique
TCL28	LP23 (105)	IITA
TCL29	IITA1 (101)	IITA
TCL31	IRMA11B (98)	CIMMYT-Kenya
TCL33	IRMA26B	CIMMYT-Kenya
TCL34	NIP25-20-1-1-B-1-B (96)	CIMMYT-Zimbabwe
TCL35	CZL04007 (92)	CIMMYT-Zimbabwe
TCL36	CML548 (93)	CIMMYT-Zimbabwe
TCL37	CML539 (89)	CIMMYT-Zimbabwe
TCL39	CML395 (83)	CIMMYT-Zimbabwe
TCL40	CML489 (87)	CIMMYT-Zimbabwe
TCL41	CML537 (88)	CIMMYT-Zimbabwe
TCL42	CML547 (90)	CIMMYT-Zimbabwe
Tester-A	CML312	CIMMYT-Zimbabwe
Tester-B	CML444	CIMMYT-Zimbabwe
Tester-AB	CML445	CIMMYT-Zimbabwe
Tester-N3	N3	AREX-Zimbabwe

Note: Numbers in brackets correspond to entry number in the genetic variability study (see Chapter 2).

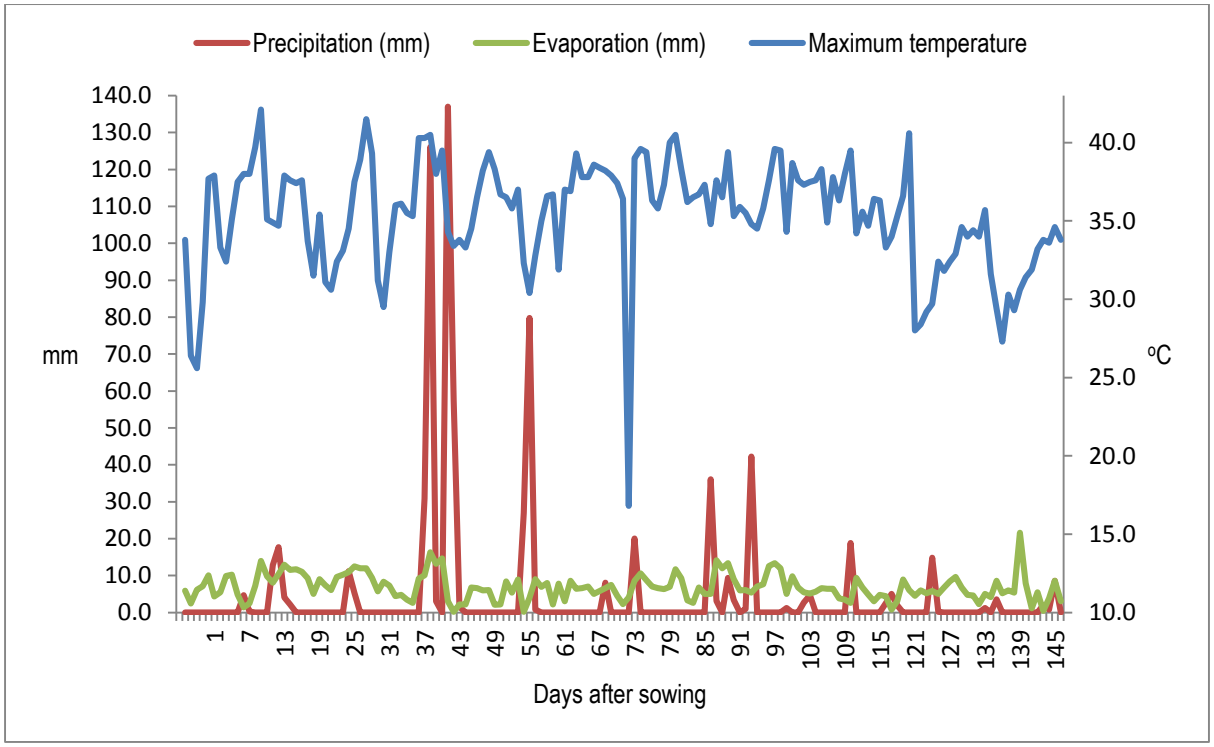

Figure 4-1. Sumary of rainfall, evapotranspiration and maximum temperature during the experimental growing period at Chokwe, 2014/15.

Sowing was by hand on November 26th, 2014. Plot size was two 5 m rows with spacing of 0.80 m and 0.25 m between and within rows, respectively, resulting in a plant density of 52,500 plants hectare^{-1}. Two border rows on each side of the experiment were planted to reduce the border effects. Fertilization was at the rate of 40 kg N, 80 kg P_2O_5 and 40 kg K_2O ha^{-1} using mineral compound 12-24-12 at sowing. Top-dress fertilization of 80 kg N ha^{-1} was done five weeks after emergence. Weed control was done using the pre-emergent herbicide bullet (alachlor, MOA 15 + atrazine, MOA 5) at a dosage of 4 litres in 300 litres of water ha^{-1}. For the purpose of this study, only data on grain yield was collected.

Data for grain yield were collected per plot basis. Two extreme plants at each end of the row were discarded to remove border effects. They were harvested a day before and their cobs were removed from the field. All ears from each plot were shelled and the grain was weighed using an electronic scale and grain moisture content was recorded. Total grain weight (GW) , grain moisture (GM) and final net plot area were used to estimate grain yield (GY) in t ha^{-1} as follow:

$$GY\ (t\,ha^{-1}) = \frac{GW\ (g)}{1000} \times \left[\frac{100 - GM\ (\%)}{100 - 12.5}\right] \times \frac{10}{\text{Net plot area}}, \text{ [Equation 4-1]}$$

4.2.3 Data Analysis

Statistical analyses were performed following PROC GLM in SAS version 9.3. First, analyses of variances (ANOVA) for agronomic performance was done to test for significance of genotypic mean squares, and then line × tester genetic analyses to partition the genotypic mean square into general combining abilities (GCA) due to lines and testers, and specific combining ability (SCA) due to testcrosses (Hallauer et al., 2010). Both analyses were done for individual and combined water-regimes, ahead designated environments. A spatial analysis using row-by-column experimental coordinates was performed. At combined environment level, significance of the testcross mean squares as well as their GCA and SCA components were tested against their corresponding interaction with environment, while pooled error was used to test the environmental and testcrosses × environment interaction mean squares (Hallauer et al., 2010).

Mathematical model for line × tester genetic analysis (Fan et al., 2009)

$y_{ijk} = \mu + l_i + t_j + (l \times t)_{ij} + \varepsilon_{ijk}$, [Equation 4-2]

where y_{ijk} is the performance of the testcross between i^{th} line and j^{th} tester, μ is the experimental mean, l_i is the general combining ability (GCA) effect of the i^{th} line, t_j is the general combining ability (GCA) effect of the j^{th} tester, $(l \times t)_{ij}$ is the specific combining ability (SCA) effect of the cross between i^{th} line and j^{th} tester.

4.2.4 Determination of heterotic orientation

The new grouping approach, heterotic specific and general combining ability (HSGCA) (Fan et al., 2009), was followed to determine heterotic orientation of the thirty inbred lines under study. Specific and general combining ability (SCA and GCA, respectively) effects as well as the HSGCA parameter of the individual line were calculated as follows:

$SCA = X_{ij} - X_{.i} - X_{j.} + X_{..}$; $GCA = X_{.i} - X_{..}$, [Equation 4-3] and

$HSGCA = GCA + SCA$, [Equation 4-4]

where X_{ij} is the mean of the testcross between i^{th} line and j^{th} tester, $X_{i.}$ is the mean of the i^{th} line, $X_{.j}$ is the mean of the j^{th} tester and $X_{..}$ is the experimental mean (intercept).

Basically, the approach consists of assigning a line to the heterotic group of the tester that resulted in the lowest HSGCA parameter. Fan et al. (2009) recommends not to classify a line

that has positive HSGCA parameter with all testers in the study as it might belong to an unknown group not represented by the testers used in a particular study.

4.3 Results

4.3.1 Agronomic performance for grain yield

Observed experimental means were 5.25 and 2.20 t ha^{-1} under non-stressed and stressed growing conditions respectively (Appendices 1a and 1b). Individual testcross (TC) means ranged from 2.32 to 8.13 t ha^{-1} under non-stressed environment, while under stressed conditions the range was from 0.75 to 3.13 t ha^{-1}. Analysis of variance for agronomic performance at individual environments detected statistically significant differences among the testcross (TC) hybrids and checks for GY under non-stressed ($p < 0.01$) and stressed ($p < 0.001$) experimental conditions (Table 4-2).

Table 4-2. Individual environment analysis of variance for grain yield of 30 x 4 testcrosses evaluated at Chókwè under unstressed and random-drought stress during the main season of 2014/15

Source of variation	DF	Non-stressed	Random drought
Replication	1	0.035	0.122
Row (Replication)	14	4.471	0.839
Column (Replication)	28	2.152	0.303
Testcross	119	1.888**	0.365***
GCA(line)	(29)	1.822*	0.698***
GCA(tester)	(3)	4.274*	0.658**
SCA(line × tester)	(87)	1.863*	0.243**
Error	61	1.072	0.118
GCA(line) / GCA(tester)		3.879	10.256
(GCAline+GCAtester) / SCA		0.386	1.050

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%.

Combined ANOVA across environments revealed that environmental mean squares were significant at $p < 0.001$ while testcross and testcross x environment mean squares were significant at $p < 0.05$ (Table 4-3). Because of the significance of environment and testcross x environment interaction effects, hybrid means were not averaged across environments (experiments) but comparisons were made at individual environmental level (Montgomery, 2005; Pimentel-Gomes, 2009).

The top 12 (10% selection intensity) combinations under non-stressed conditions were TCL28/CML312, TCL26/N3, TCL23/CML444, TCL11/CML445, TCL36/CML312,

Table 4-3. Combined environment analysis of variance for grain yield of 30 x 4 testcrosses evaluated at Chókwè under unstressed and random-drought stressed conditions during the main season of 2014/15.

Source	DF	MS
Environment (Environment)	1	1209.453***
Rep (Environment)	2	0.078
Incomplete blocks	30	1.273**
Row (Replication × Environment)	14	1.236*
Column (Replication × Environment)	58	1.243***
Testcross	119	1.368*
Testcross × Environment	119	0.901*
GCAline	(29)	1.862**
GCAtester	(3)	4.086
SCA(line × tester)	(87)	1.110**
GCAline × Environment	(29)	0.701
GCAtester × Environment	(3)	1.125
SCA(line × tester) × Environment	(87)	0.960*
Error	136	0.634
GCA(line) / GCA(tester)		4.405
[GCA(line) + GCA(tester)] / SCA		0.686

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%.

TCL34/CML445, TCL26/CML312; TCL4/CML312, TCL37/N3, TCL39/CML312, TCL31/CML312, TCL40/CML445 and TCL36/CML444 at descending order. Under stressed conditions the highest performers were TCL29/CML444, TCL33/CML312, CML445/CML444, TCL39/CML312, CML312/CML445, TCL28/CML312, TCL7/CML445, TCL7/CML312, TCL26/CML445, CML442/CML539 (check), TCL35/CML312 and TCL36/CML312 in descending order.

4.3.2 Line × tester combining ability and heterotic orientation

Results from individual experiments (Table 4-2) indicated that GCAs and SCA mean squares were significant at $p < 0.05$ under non-stressed condition but were highly significant ($p < 0.001$ for line-GCA, and $p < 0.01$ for tester-GCA and line × tester-SCA) under stressed environment. Combined analysis detected significant line-GCA and testcross SCA ($p < 0.01$) but not tester-GCA ($p > 0.05$). The interaction between line GCA × environment was not statistically significant but SCA × environment was significant at $p < 0.05$. Based on the ANOVA results, the general combining ability effects that finally characterise individual lines can be better estimated using across environment performance but it seems that specific combining abilities of the individual combinations vary depending on the growing conditions (Table 4-3).

Ten lines had positive GCA effects under both non-stressed and stressed conditions, resulting in positive, significant GCA effects when data from the two experiments were combined. These were TCL26, 36, 28, 7, 35, 34, 29, 39, 33 and 25 and the GCA effects varied from 0.666 to 0.225 (Table 4-4). Line × tester (SCA) effects estimates varied. Best combinations under unstressed conditions were TCL11/CML445, TCL23/CML444, TCL4/CML312, TCL28/CML312, TCL26/N3, TCL34/CML445 and TCL41/CML445 with positive SCA effects varying from 2.743 to 1.421. Under stressed experimental conditions, values of SCA effects were very low. The best combinations were TCL41/CML444, TCL11/CML312, CML27/N3, TCL42/CML445, TCL41/CML445, TCL31/CML312 and TCL4/CML312. Their SCA effects varied from 0.904 to 0.667.

Table 4-5 presents the heterotic orientation resulting from the application of the HSGCA as proposed by Fan et al. (2008b) and Fan et al. (2009). It was observed that eleven lines were oriented towards N3, seven towards CML312, seven towards CML445 and five towards CML444 under unstressed experimental conditions (Appendix 1a). Under stressed conditions (Appendices 1b) 20 lines changed their orientation. As a result, nine lines were towards CML444, eight towards CML312, seven towards N3 and six were towards CML445.

Table 4-4. Estimates of GCA effects for 30 maize inbred lines and their SCA effects with four testers under non-stressed and stressed conditions.

Lines	GCA-effects			SCA-effects (non-stressed)				SCA-effects (stressed)			
	Non-stressed	**Stressed**	**Across**	CML312	CML444	CML445	N3	CML312	CML444	CML445	N3
TCL1	-0.254	-0.010	-0.132	0.355*	-0.851**	0.436*	0.059	0.107	-0.088	-0.092	0.073
TCL2	-0.698**	0.104	-0.297	0.495*	0.012	0.104	-0.611**	-0.009	-0.291	0.191	0.109
TCL3	-0.447*	-0.049	-0.248	0.409*	-1.656***	0.291	0.956**	0.136	0.091	0.214	-0.441
TCL4	-0.975**	-0.453*	-0.714**	2.113***	-0.345*	-0.878**	-0.890**	0.667**	0.029	-0.351*	-0.345*
TCL6	-0.062	-0.225	-0.143	0.790**	-0.155	0.288	-0.922**	-0.323*	0.141	-0.083	0.265
TCL7	0.309*	0.512*	0.410*	-1.351***	1.018***	-0.007	0.339*	-0.012	-0.017	0.164	-0.136
TCL9	0.542*	-0.158	0.192	-0.076	-1.005***	0.284	0.797**	-0.349*	0.230	-0.300*	0.418*
TCL10	-0.060	0.123	0.032	0.493*	-0.663**	-0.373*	0.544*	0.239	-0.299	0.034	0.025
TCL11	-0.292	-0.720**	-0.506*	-0.417*	-2.173***	2.743***	-0.153	0.746**	-0.280	-0.620**	0.153
TCL12	-0.315*	-0.123	-0.219	0.579*	-0.038	-0.855**	0.313*	0.365*	0.296	-0.376*	-0.285
TCL14	0.390*	-0.055	0.168	-0.515*	0.094	0.349*	0.073	0.228	0.204	-0.460*	0.028
TCL18	-0.078	0.056	-0.011	0.836**	-0.189	-0.979**	0.332*	-0.167	0.306*	0.331*	-0.470*
TCL21	-0.096	-0.400*	-0.248	-0.225	0.165	0.433*	-0.374*	-0.461*	-0.150	0.185	0.426*
TCL23	-0.151	-0.232	-0.191	-0.215	2.608***	-1.481***	-0.912**	0.349*	-0.694**	0.154	0.192
TCL24	-0.441*	0.149	-0.146	-0.748**	0.716**	0.162	-0.130	-0.446*	0.311*	-0.131	0.266
TCL25	0.023	0.426*	0.225	-0.289	0.304*	0.031	-0.047	-0.010	0.126	-0.334*	0.218
TCL26	1.027***	0.305*	0.666**	0.121	-0.061	-1.731***	1.670***	-0.235	-0.038	0.290	-0.017
TCL27	-0.488*	-0.090	-0.289	0.119	0.151	0.032	-0.302*	-0.234	-0.553*	0.249	0.538*
TCL28	0.644**	0.239	0.441*	1.861***	-0.424*	-1.795***	0.359*	0.340*	0.331*	-0.475*	-0.196
TCL29	0.225	0.350*	0.288	-0.140	0.663**	-0.101	-0.422*	-0.549*	0.611*	-0.080	0.018
TCL31	0.046	-0.324*	-0.139	0.966**	0.276	-0.435*	-0.807**	0.720**	-0.275	-0.218	-0.226
TCL33	0.218	0.309*	0.264	-0.253	0.028	-0.036	0.260	0.465*	0.070	-0.227	-0.309*
TCL34	0.320*	0.354*	0.337*	-1.162***	-0.525*	1.501***	0.187	-0.057	-0.257	0.200	0.114
TCL35	0.322*	0.477*	0.400*	0.220	-0.362*	-0.596*	0.738**	-0.018	-0.272	0.007	0.283
TCL36	0.981**	0.266	0.624**	0.404*	0.396*	0.019	-0.819**	0.187	0.103	0.262	-0.552*
TCL37	0.478*	-0.241	0.119	-2.251***	0.442*	0.589*	1.221***	-0.963**	0.292	0.201	0.470*

TCL39	0.430*	0.139	0.284	0.601**	0.820**	0.058	-1.479***	0.531*	-0.319*	-0.157	-0.055
TCL40	0.385*	-0.033	0.176	-0.556*	0.578*	1.090***	-1.112***	0.329*	-0.452*	0.355*	-0.233
TCL41	-1.194***	-0.613**	-0.904**	-2.110***	0.009	1.427***	0.674**	-0.983**	0.904**	0.533*	-0.454*
TCL42	-0.790**	-0.084	-0.437*	-0.054	0.166	-0.571**	0.458*	-0.592*	-0.061	0.534*	0.120

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%.

Table 4-5. Heterotic orientation of thirty maize inbred lines towards CML312, CML444, CML445 and N3 under non-stressed versus stressed condition at Chokwe, 2014/15 main season.

	Non-stressed experiment			Stressed experiment		
Lines	**SCA**	**HSGCA**	**Heterotic orientation**	**SCA**	**HSGCA**	**heterotic orientaion**
TCL1	-0.85**	-1.14	CML444	-0.088	-0.119	CML444
TCL2	-0.61**	-1.53	N3	-0.291	-0.209	CML444
TCL3	-1.66***	-2.13	CML444	-0.441*	-0.664	N3
TCL4	-0.89**	-2.08	N3	-0.345*	-0.972	N3
TCL6	-0.92**	-1.20	N3	-0.323*	-0.398	CML312
TCL7	-1.35***	-0.66	CML312	-0.136	0.202	N3
TCL9	-1.01***	-0.50	CML444	-0.300	-0.412	CML445
TCL10	-0.66**	-0.76	CML444	-0.299	-0.197	CML444
TCL11	-2.17***	-2.50	CML444	-0.620**	-1.294	CML445
TCL12	-0.85**	-1.29	CML445	-0.376*	-0.453	CML445
TCL14	-0.52*	0.25	CML312	-0.460*	-0.469	CML445
TCL18	-0.98**	-1.18	CML445	-0.470*	-0.588	N3
TCL21	-0.37*	-0.69	N3	-0.461*	-0.711	CML312
TCL23	-1.48***	-1.76	CML445	-0.694**	-0.947	CML444
TCL24	-0.75**	-0.81	CML312	-0.446*	-0.147	CML312
TCL25	-0.05	-0.24	N3	-0.334*	0.138	CML445
TCL26	-1.73**	-0.83	CML445	-0.235	0.220	CML312
TCL27	-0.30	-1.01	N3	-0.553**	-0.664	CML444
TCL28	-1.80***	-1.28	CML445	-0.475*	-0.191	CML445
TCL29	-0.42*	-0.42	N3	-0.549**	-0.049	CML312
TCL31	-0.81**	-0.98	N3	-0.226	-0.724	N3
TCL33	-0.25	0.34	CML312	-0.309*	-0.174	N3
TCL34	-1.16**	-0.46	CML312	-0.257	0.076	CML444
TCL35	-0.60*	-0.40	CML445	-0.272	0.183	CML444
TCL36	-0.82**	-0.06	N3	-0.552**	-0.460	N3
TCL37	-2.25***	-1.40	CML312	-0.963**	-1.054	CML312
TCL39	-1.48***	-1.27	N3	-0.319*	-0.201	CML444
TCL40	-1.11***	-0.95	N3	-0.452*	-0.505	CML444
TCL41	-2.11**	-2.93	CML312	-0.983**	-1.446	CML312
TCL42	-0.57**	-1.49	CML445	-0.592**	-0.527	CML312

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%.

In yellow are the cases in which yield-SCA was used rather than HSGCA.

4.4 Discussion

4.4.1 Agronomic performance

In general, although the growing season was hot and rainy, drought spells occurred during the grain filling stage (Figure 4-1). Consequently, a degree of stress resulting from a combination of high temperatures and random-drought was experienced for the experiment in which irrigation was stopped at 40 days after emergence. Under fully-irrigated conditions, anthesis occurred between 48 to 59 days after emergence and number of days to silking ranged from 50 to 63 (Appendices 1a and 1b). Under RDS, flowering delayed by about 9 days on average compared to fully-irrigated experiment. The ranges varied from 53 to 63 days for number of days to anthesis (AD) and 60 to 69 days for number of days to silking (SD). But what is more important is ASI which is the interval between AD and SD. The average ASI was larger under RDS (6.3 days), with a range of 1 to 10 days, than in the fully-irrigated experiment (average ASI of 2.5 days), with a range of -3 to 8 days.

Although the observed average ASI under RDS was within the range considered for severe drought stress category by Bänziger et al. (2000), the number of ears plant^{-1} (average of 1.06) was not significantly different from the one under fully-irrigated experiment (1.10). This explains why grain yield reduced by a level of 58%, considered to moderate stress by the above cited source. Therefore, the comparison made in this study in terms of heterotic orientation refers to warm well-watered versus combined moderate heat-drought stress conditions.

The highly significant environmental mean squares for GY ($p < 0.001$) indicate that the water-regimes contributed significantly to the total variation observed in the hybrid performance across the two experiments. This is similar to findings of Bello and Olaoye (2009). On the other hand, the change on the level of significance of testcross mean squares from $p < 0.01$ under well-watered to $p < 0.001$ under RDS and the significance of testcross × environment interaction revealed that the different growing conditions, caused by difference in water-regime, had significant impact on the magnitude of differences among testcrosses at particular environment. This is similar to Fan et al. (2014). As a result, testcross ranking changed from well-watered to moderate random drought stress experiments of this study as it can be seen from the top yielders listed in the result section. The results suggest that genetic properties of the inbred lines should be looked at first under individual environmental conditions.

4.4.2 Combining ability

The highly significant testcross effects to the total variability observed under well-watered experimental condition was due to significant GCA-lines, GCA-testers and SCA-line × tester effects as all the three genetic components were equally significant at $p < 0.05$ (Table 4-2). However, the ratio between the sum of squares due to GCA and sum of squares due to SCA (SSgca (line + tester)/SSsca) was very low (0.386) (Table 4-2). This indicates that the effects due to SCA were more important than the effects due to GCA of the lines under well-watered conditions. The proportions of the genetic components changed under stress conditions. The ratio between the total GCA and SCA increased to 1.050 (Table 4-2), indicating that the importance of the two genetic components was equal. In both environments, the lines contributed more than the testers. Under well-watered conditions, line effects were almost four times larger compared to the tester effects and under stressed condition line effects were ten times larger.

The results agreed with many genetic studies conducted in factorial and diallel mating designs on maize, but it also disagreed with some. Agreement is with results from Fan et al. (2008a), Pswarayi and Vivek (2008), Bello and Olaoye (2009), Mhike et al. (2011), Badu-Apraku et al. (2013), Adebayo et al. (2014), Oyekunle and Badu-Apraku (2014) and Badu-Apraku et al. (2015) in terms of both GCA and SCA effects being important but with predominance of GCA. Results from the study by Derera et al. (2008) are well in line with the findings of the present study because larger contribution of SCA than GCA effects was found under non-stressed conditions while under drought-stress conditions GCA effects contributed more. Akbar et al. (2008) also reported results showing predominance of GCA effects under heat stress while both GCA and SCA effects were equally important under normal temperature conditions. Under low-nitrogen and drought (separated) stress conditions, Makumbi et al. (2011) reported larger proportions of GCA than SCA but under optimum conditions SCA over-expressed GCA. In some studies like those of Fan et al. (2004), Zare et al. (2011), Estakhr and Heidari (2012) and Abdel-Moneam et al. (2014) only SCA was important for grain yield in maize.

The findings from this study show that the proportions of the genetic components depend upon the number and genetic background of the parents used, as well as the environmental conditions under which the genotypes are tested and hence confirm findings of Hallauer (2007). Thus heterotic relationships are expected to change when environmental conditions change.

It is important to highlight that among the ten inbred lines that had positive GCA effect under both full irrigation and stressed experimental conditions, five were identified as potential new elite lines. These are TCL26 (IL-108), TCL7 (IL-31), TCL35 (IL-92), TCL29 (IL-101) and TCL25 (IL-107). This suggests that the five lines have potential to be used not only as parents for future hybrid cultivars but also as parents for future breeding for drought tress tolerance.

4.4.3 Heterotic orientation

Combination of the new approach “heterotic group's specific and general combining ability” (HSGCA) as applied by Akinwale et al. (2014) and the traditional yield-SCA method (Hallauer, 2007) were used in order to relate the thirty maize female lines to four male lines considered as testers. Fan et al. (2008b) and Fan et al. (2009) reported higher efficiency of HSGCA method compared to the traditional yield-SCA and molecular marker methods on assigning maize inbred lines to heterotic groups. However, it is acknowledged that no one heterotic group classification method is perfect because of the unlimited genetic combinations in any particular cross. Therefore, it was decided to combine the HSGCA and yield-SCA methods to effectively relate the female lines to four testers. The traditional yield-SCA method was used to assign a line to heterotic group in the cases when its HSGCA was positive with the four testers but it had negative yield-SCA with at least one tester. This occurred once under fully-irrigated and four times under stressed conditions (Table 4-5).

Majority of the lines (67%) changed their orientations towards a tester on moving from fully-irrigated to stressed experimental conditions. This can complicate breeding for both stressed and non-stressed environments. Breeding for specific environment would reduce the size of product market for a variety and seed companies might to be encouraged to commercialise that variety. Therefore, the ideal breeding goal would be to identify stable heterotic testers across contrasting environments and to select newly developed inbred lines that don not change their heterotic orientation when moving from non-stressed to moderate and severe stress conditions. In this study, only two out of thirty testcrossed inbred lines maintained their orientation towards a tester under both stressed and non-stressed environments. Those were TCL28 and TCL36.

Under full irrigation, tester N3 was related with 11 lines (37%) while under stressed conditions only 7 (23%) lines were found related with this tester. On the other hand, only 5 lines (17%) were assigned to the same group as CML444 under fully-irrigated condition but nine lines (30%) were assigned in the same group with it under stressed experimental

condition. Both N3 and CML444 are dent-grain type and they discriminated some of the lines differently under the two different environmental conditions. The potential of N3 to generate high yielding hybrids under favourable environments is accepted in the Southern Africa Region while CML444 is very popular drought stress tolerant tester.

Testers CML312 and CML445 tended to be more stable across the two experimental conditions. They are also popular drought tolerant parents of many hybrids developed by CIMMYT. Each of the two testers were related with seven lines (23%) under fully-irrigated condition and changed to more or less by one line under stressed conditions. The two testers are flint-grain type, thus, they just discriminated the remaining lines that were not able to be effectively discriminated by N3 and CML444.

4.5 Conclusion

The objective of this study was to determine the heterotic orientation of selected inbred lines towards three popular drought tolerant testers (CML312, CML444 and CML445) and towards the high yielding potential tester N3. Using the HSGCA approach and the yield-SCA, the four testers effectively discriminated the thirty inbred lines of this study.

It was found that heterotic orientation changed significantly with change in environmental conditions. Twenty inbred lines (67%), including eight best GCA combiners, changed from one tester to another when experimental conditions changed from fully-irrigated to random and moderate drought stress. Only TCL28 and TCL36 did not change. These two lines have the second and third best GCA effect estimates for grain yield.

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5. CHAPTER 5. Correlation and path coefficient analysis of maize grain yield with other characteristics under fully-irrigated versus water-limited conditions

Abstract

Correlation and path coefficients between maize (*Zea mays* L.) grain yield (GY) and other traits under contrasting environments are important statistical parameters that help understanding the strength of relationship and the level of contribution of the secondary traits to GY under these different environments. The objective of this study was to assess the level of relationship between maize traits correlated with GY in inbred lines *per se* versus hybrids under stressed and non-stressed conditions. Data from two types of experimental trials grown under full irrigation and water-limited conditions were used. One trial consisted of 128 inbred lines and the other of 48 F_1 hybrids. Line *per se* trial was evaluated at two sites in Zimbabwe under severe heat-drought stress (SHDS) at Chiredzi, moderate heat-drought stress (MHDS) at Save Valley, and one site in Mozambique at Chókwè under random-drought stress (RDS) and non-stressed conditions. The hybrid trial was conducted at Chókwè under moderate combined heat-drought stress (CHDS), isolated heat stress (IHS), isolated drought stress (IDS) and non-stressed conditions. Drought environments were manipulated by withdrawing irrigation 40 days after emergence while the non-stressed environment at Chókwè was achieved by providing water until physiological maturity. In general, genetic correlation and path coefficients analyses revealed positive and significant relationship between GY and number of ears plant^{-1} (EPP) and ear aspect (EA) under almost all environments in both the inbred and hybrid trials. This implies that EPP and EA can be used as indirect selection traits when breeding maize for combined heat and drought conditions. The study also identified direct positive contribution of smaller anthesis-silking intervals (ASI) to GY under severe stresses but only indirectly through number of grains ear^{-1} (NGPE) under less stressed environments. The NGPE had strong positive direct effect on GY while 100-grain weight contributed only indirectly through NGPE in hybrids. Therefore, EPP, EA, ASI and NGPE would be useful as secondary traits for maize grain yield selection for combined heat-drought stress breeding.

5.1 Introduction

Although maize is the primary food crop of Mozambique, yields in farmers' fields have remained below 1 t ha^{-1} (FAOSTAT, 2015) This is basically due to two main environmental constraints: i) maize sensitivity to high temperatures that characterizes the main growing season (Harrison et al., 2011) in Mozambique; and ii) unreliable rainfall distribution and frequent drought spells (INGC, 2010). Therefore, the development of combined stress tolerant maize germplasm is of paramount importance so as to ensure stable yields under farmers' field conditions (Cairns et al., 2012; Cairns et al., 2013a; Cairns et al., 2013b). As a primary trait, grain yield in maize is a complex polygenic character, with low heritability and hence difficult to select for. Therefore, progress in selection for GY under combined drought and heat could be achieved by indirect selection via highly heritable secondary traits that may directly influence yield.

In addition, use of secondary traits for indirect selection of germplasm tolerance has been advocated by many plant breeders and physiologist who targeted improvement of maize yield in abiotic stressed environments (Araus and Sanchez, 2012; Bänziger et al., 2000; Bavei et al., 2011; Betrán et al., 2003; Bolaños and Edmeades, 1996; Chimenti et al., 2006; Fischer et al., 1982; Fokar et al., 1998; Kebede et al., 2012; Liu et al., 2011; Lopes et al., 2011; Maestri et al., 2002; Messmer et al., 2009; Mhike et al., 2012; Molina-Bravo et al., 2011; Obeng-Bio et al., 2011; Reynolds and Trethowan, 2007; Ribaut et al., 1996; Ristic et al., 1998; Schoper et al., 1987; Sinclair, 2011; Takele, 2010; Talebi, 2011; Tollenaar and Lee, 2002; Tollenaar and Lee, 2006; Vaezi et al., 2010; Wahid et al., 2007; Weber et al., 2012; Zaidi et al., 2004; Zhuan-Fang et al., 2011). Bänziger et al. (2000) working with maize, Fischer et al. (2003) in rice and Reynolds et al. (2001) in wheat gave practical recommendations for the use of secondary traits in breeding for drought, low soil fertility and heat stress tolerance. In general, these researchers highlighted that a useful secondary trait must be; 1) genetically correlated with grain yield in the stress under consideration, 2) less affected by environment (low genotype-by-environment interaction) when compared with grain yield (the trait must exhibit greater heritability than grain yield under stress), 3) faster, easier and not expensive to measure compared to assessing grain yield, and 4) easily assessed in individual plants or in very small plots.

Bänziger et al. (2000) demonstrated that the number of ears per plant, anthesis-silking interval, leaf rolling, leaf senescence and tassel size were the most useful secondary traits to identify drought tolerance in maize. In addition, Mhike et al. (2012) validated the use of secondary traits and selection indices for drought tolerance in tropical maize and concluded that anthesis-silking interval and number of ears $plant^{-1}$ were the most valuable secondary

traits because they were consistently and strongly correlated with grain yield. New developments in research addressing both drought and heat tolerance indicate that drought tolerance does not necessarily indicate heat tolerance (Cairns et al., 2013a; Prasad et al., 2008). This is because the molecular and biochemical responses of plants to a combination of the two stresses are unique and cannot be extrapolated simply from responses to the individual stresses (Mittler, 2006).

Although plant stand is the first and most important yield component, it is not recommended as a secondary trait for drought stress tolerance (Araus and Sanchez, 2012). This is because the trait is more useful at early stages, during crop establishment, and genetic variation for number of plants due to drought stress is insignificant (Bänziger et al., 1996). Bänziger et al. (1996) authors concluded that natural selection may have already exploited most of the genetic variation for this trait. However, a study by Meeks et al. (2013) reported the importance of seedling stress response as a secondary screening parameter. In that study, it was found that seedling drought response was more important in hybrids than in inbred lines but the response mechanisms at seedling stage were independent from those at flowering stages in both inbred and hybrid genotypes. Nevertheless, Araus and Sanchez (2012) pointed out that the later stages (from flowering to grain filling) are more important and may result in a complete loss of season because replanting would no longer possible.

Reliable secondary traits under drought stress alone were validated by Badu-Apraku et al. (2012). Badu-Apraku et al. (2012) suggested that anthesis-silking interval, plant height, ear placement, ears plant^{-1}, plant aspect and ear aspect were more important when stress occurred at flowering stage, but the importance of leaf senescence was not confirmed. On the other hand, Mhike et al. (2012) validated the use of some secondary traits and selection indices for drought tolerance in tropical maize. The stress in the study by Mhike et al. (2012) was also under drought stress alone. Ears plant^{-1} and anthesis-silking interval were the only traits reported to have a strong relationship with grain yield under stress. Genetic variance for leaf senescence was again not statistically significant.

Since droughts occur simultaneously with heat during the main maize cropping seasons in the tropical and subtropical environments, it is important to know whether the traits correlated with grain yield under drought alone will remain the same under combined heat and drought stress conditions. To answer this question, a study under drought stress alone, heat stress alone and combined heat and drought stress conditions is necessary.

Studies on the relationship among traits in crop species are made through analyses of their coefficients, either phenotypic or genotypic correlations, or path coefficients. Correlation

coefficient analysis is simply a measurement of mutual association but it disregards complex interrelationships among traits (Alhassan et al., 2008). For this reason, use of path coefficient analysis has lately become more popular (Adesoji et al., 2015; Ahmad and Saleem, 2003; Khalili et al., 2013; Kumar et al., 2015; Mustafa et al., 2014; Wannows et al., 2010). Conceptually, "path coefficient analysis is a standard partial regression that measures the direct and indirect effects for a set of priori cause-and-effect interrelationship" (Alhassan et al., 2008). The objective of this study was to determine the relationship among maize traits correlated with grain yield in both inbred lines and hybrids under full irrigation and water-limited conditions.

5.2 Materials and Methods

5.2.1 Data

Data from two different trials, namely inbred lines *per se* trial (Chapter 2) and diallel cross hybrids trial (Chapter 3) were used for this study. The inbred line trial was conducted under managed severe heat and drought stress (SHDS), managed moderate heat and drought stress (MHDS), random drought stress alone and non-stressed conditions. The hybrid trial was conducted under MHDS, heat stress alone (HS), drought stress alone (DS) and non-stressed conditions. The inbred lines *per se* trial consisted of 128 genotypes and the hybrid trial was formed by 45 diallel crosses plus three checks resulting in 48 F_1 crosses. Details on the experiment evaluations and data collection were provided in the two chapters mentioned above. The target traits for correlation and path coefficient analyses were number of ears plant^{-1} (EPP), number of grains ear^{-1} (NGPE), weight of 100 grains (W100G), number of days to anthesis (AD), anthesis-silking interval (ASI), plant height (PH), ear position (EPO), plant aspect (PA) and ear aspect (EA).

5.2.2 Correlation and path coefficient analyses

Before conducting correlation and path coefficient analyses, analyses of variance (ANOVAs) at individual environments were performed in each set of data. The ANOVAs were conducted in Fieldbook-IMIS5 free statistical software developed by CIMMYT (Bänziger et al., 2012).

Pearsons' phenotypic correlation [$r_{p(xy)}$] analysis was performed among the traits using PROC CORR in the SAS 9.3 statistical software. Significance of the difference of each correlation coefficient from zero was tested using a t-test. Genetic correlations [$r_{G(xy)}$] were

estimated as described by Kearsey and Pooni (1996). In order to know what secondary trait has a direct influence on the yield under stressed conditions, phenotypic and genotypic correlations were further partitioned into direct and indirect influences through path coefficient (cause-effect relationship) analysis as applied by Adesoji et al. (2015) and Kumar et al. (2015).

$$r_{P(xy)} = \frac{\sigma^2_{Pxy}}{\sqrt{\sigma^2_{P(xx)} \times \sigma^2_{P(yy)}}}$$, [Equation 5-1] and

$$r_{G(xy)} = \frac{\sigma^2_{Gxy}}{\sqrt{\sigma^2_{G(xx)} \times \sigma^2_{G(yy)}}}$$, [Equation 5-2]

for phenotypic and genotypic correlation coefficients respectively, where σ^2_{xy} is the covariance between two traits being correlated, σ^2_{xx} is the variance of xth trait, and σ^2_{yy} is the variance of the yth trait.

Path coeficients were calculated using Excel programme as follows:

$$r(X_1, Y) = \frac{\sigma_{X1}}{\sigma_Y} + r(X_1, X_2)\frac{\sigma_{X2}}{\sigma_Y} + ... + r(X_1, X_N)\frac{\sigma_N}{\sigma_Y}$$, [Equation 5-3]

5.3 Results

5.3.1 Analyses of variance

Results from the inbred lines *per se* trial are summarised in Tables 5-1. Analysis of variance (ANOVA) revealed that genotypic variances for grain yield (GY) were statistically significant at $p < 0.01$ under severe heat-drought stress (SHDS) and at $p < 0.001$ under the other three environments (moderate heat-drought stress, random drought stress and unstressed environment). For number of ear plant^{-1} (EPP) variances were significant at $p < 0.001$ under SHDS and $p < 0.01$ under the rest of the three environments. Number of grains ear^{-1} (NGPE) and weight of 100 grains (W100G) were assessed only at the two environments in Chókwè, namely random drought stress (RDS) and non-stressed, and the ANOVA detected significant genotypic variances at $p < 0.001$ for the two traits under these two environments.

Table 5-1. Summary of the analyses of variance for grain yield and associated traits of 108 maize inbred lines evaluated under four different environments in 2014.

Environment	Trait	GY (t ha^{-1})	EPP (ratio)	NGPE (#)	W100G (g)	AD (days)	ASI (days)	PH (cm)	EA (1-5)
Severe heat-drought stress (SHDS) = Chiredzi	Genotype	0.284	0.044	-	-	34.232	19.963	298.926	0.426
	Error	0.132	0.022	-	-	6.605	7.519	295.253	0.162
	Significance	**	**	-	-	***	*	ns	***
Moderate heat-drought stress (MHDS) = Save Valley	Genotype	0.498	0.084	-	-	11.741	3.487	428.89743	0.651
	Error	0.228	0.048	-	-	3.824	1.391	291.085	0.327
	Significance	***	**	-	-	***	*	*	**
Random drought stress (RDS) =Chokwe	Genotype	0.237	0.063	0.995	17.359	17.707	4.820	-	0.934
	Error	0.059	0.030	0.387	2.127	0.963	0.607	-	0.458
	Significance	***	**	***	***	***	***	-	***
Non-stressed = Chokwe	Genotype	1.562	0.066	1089.721	15.426	16.397	2.470	501.726	0.651
	Error	0.368	0.023	0.401	1.899	1.142	0.900	339.782	0.369
	Significance	***	***	***	***	***	***	*	*

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant^{-1}; **NGPE** = number of grains ear^{-1}; **W100G** = weight of 100 grains; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EA** = ear aspect.

Significance at $p < 0.001$ was detected for number of days from emergence to 50% anthesis (AD) under the four experimental environments of the inbred trial. For anthesis-silking interval (ASI), significance was at $p < 0.05$ under the two environments in Zimbabwe (SHDS and MHDS) and at $p < 0.001$ under the two environments at Chókwè (RDS and non-stressed). Statistical significance for plant height (PH) was revealed under MHDS and non-stressed environments ($p < 0.05$) but not under SHDS ($p > 0.05$). Significant genotypic variances were also observed for ear aspect (EA) under SHDS and RDS ($p < 0.001$), MHDS ($p < 0.01$) and unstressed ($p < 0.05$).

From the diallel cross hybrid trial, results of ANOVA were summarised in Table 5-2. Statistically significant genotypic variances for GY were observed at $p < 0.01$ under combined heat-drought stress (CHDS) and at $p < 0.001$ under isolated heat stress (IHS), isolated drought stress (IDS) and unstressed environments. Significance for EPP was detected only under IDS ($p < 0.05$) and not under the other three environments. In addition, significance at $p < 0.001$ was detected for NGPE and W100G under the environments where they were assessed (CHDS, IDS and unstressed).

For AD, significance was at $p < 0.001$ under IDS and IHS, at $p < 0.01$ under CHDS and at $p < 0.05$ under non-stressed conditions. Analysis of variance did not detect statistical

significance for ASI under HS and non-stressed experimental conditions of the diallel cross hybrid trial but yes under DS ($p < 0.001$) and CHDS ($p < 0.05$).

Table 5-2. Summary of the analyses of variance for grain yield and associated traits of 45 maize diallel single crosses evaluated under four different environments in 2014.

Environment	Trait	GY (t ha^{-1})	EPP (ratio)	NGPE (#)	W100G (g)	AD (days)	ASI (days)	PH (cm)	PA (1-5)	EA (1-5)
Combined heat-drought stress (CHDS) = Chókwè	Genotype	0.341	0.019	-	-	6.080	1.307	410.166	0.496	0.358
	Error	0.161	0.015	-	-	2.828	0.815	91.506	0.295	0.188
	Significance	**	ns	-	-	**	*	***	*	**
Heat stress alone (HS) = Chókwè	Genotype	1.029	0.028	11045.718	19.22	4.233	2.303	455.779	-	-
	Error	0.086	0.018	1514.777	2.200	1.397	2.277	297.881	-	-
	Significance	***	ns	***	***	***	ns	*	-	-
drought stress alone (DS) = Chókwè	Genotype	2.151	0.013	12396.465	17.183	5.373	6.321	483.304	-	0.581
	Error	0.362	0.009	806.466	2.039	1.432	2.742	313.970	-	0.448
	Significance	***	*	***	***	***	***	*	-	ns
Non-stressed = Chókwè	Genotype	2.050	0.016	13429.256	19.153	10.730	0.413	488.705	0.705	0.767
	Error	0.315	0.015	1850.886	3.944	7.059	0.549	158.965	0.432	0.288
	Significance	***	ns	***	***	*	ns	***	*	***

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant^{-1}; **NGPE** = number of grains ear^{-1}; **W100G** = weight of 100 grains; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EA** = ear aspect.

For PH, ANOVA revealed statistical significance at $p < 0.001$ under CHDS and non-stressed, and at $p < 0.05$ under HS and DS conditions. Plant aspect (PA) was scored under CHDS and non-stressed conditions, and genotypic variances were significant under both conditions for this trait ($p < 0.05$). Genotypic variances for ear aspect were found significant under CHDS ($p < 0.01$) and non-stressed ($p < 0.001$) but not under DS ($p > 0.05$).

5.3.2 Correlations and path coefficient analyses between grain yield and other traits

Inbred lines *per se*: Table 5-3a shows the results on correlation coefficient (phenotypic and genotypic) analyses from the inbred *per se* trial data. Highly significant ($p < 0.001$) positive genetic correlations between EPP and GY were observed under SHDS, MHDS and non-stressed conditions but under RDS genetic correlation was statistically significant at $p > 0.05$. Phenotypic correlation was highly significant between EPP and GY under RDS and non-stressed ($p < 0.001$). For NGPE, both phenotypic and genotypic correlation coefficients

were significant at $p < 0.001$ under both the stressed and non-stressed environments of Chókwè, while for W100G only genotypic correlation under RDS was significant ($p < 0.05$).

Number of days to anthesis was consistently negatively correlated with GY in the inbred trial and the coefficients were all highly significant ($p < 0.001$) except the genotypic coefficients under SHDS and MHDS ($p > 0.05$).

Table 5-3a. Phenotypic (below diagonals) and genotypic (above diagonals) correlation coefficients among maize traits of 108 inbreds evaluated in four different environments.

Severe heat-drought stress (SHDS) – Chiredzi, 2014

	GY	AD	ASI	PH	EPP	EA
GY	**1**	-0.181	-0.122	0.156**	0.548***	-0.659***
AD	-0.566***	**1**	-0.444***	0.085	-0.161	0.358***
ASI	-0.010	-0.129	**1**	-0.027	-0.066	-0.034
PH	-0.283***	-0.050	-0.677***	**1**	0.054	-0.176
EPP	0.006	-0.017	0.020	-0.279**	**1**	-0.290**
EA	0.014	-0.055	0.833***	-0.547***	-0.030	**1**

Moderate heat-drought stress (MHDS) – Save Valley, 2014

	GY	AD	ASI	PH	EPP	EA
GY	**1**	-0.111	-0.167	0.324***	0.590***	-0.686***
AD	-0.401***	**1**	-0.075	0.097	0.137	0.047
ASI	-0.119	0.149*	**1**	0.071	-0.205*	0.018
PH	0.401***	-0.574***	-0.540***	**1**	0.153	-0.157
EPP	0.044	0.264**	0.896***	-0.545***	**1**	-0.249*
EA	-0.234**	0.600***	-0.068	-0.612***	0.033	**1**

Random drought stress (RDS) – Chókwè, 2014/15

	GYG	AD	ASI	EPP	EA	NGPE	W100G
GYG	**1**	-0.437***	-0.425***	-0.141*	-0.420***	0.772***	0.194**
AD	-0.364***	**1**	0.053	0.125	0.166**	-0.350***	-0.130*
ASI	-0.542***	0.078	**1**	-0.375***	0.352***	-0.336***	0.308**
EPP	0.421***	-0.210**	-0.182*	**1**	-0.358***	-0.253**	-0.760***
EA	-0.466***	0.191*	0.23**	-0.128	**1**	-0.469***	0.311***
NGPE	0.756***	-0.254**	-0.428***	-0.079	-0.451***	**1**	0.073
W100G	-0.0294	0.030	0.035	0.034	0.027	-0.304**	**1**

Non-stressed – Chókwè well-watered, 2014/15

	GYG	AD	ASI	PH	EPP	EA	NGPE	W100G
GYG	**1**	-0.422***	-0.057	0.262**	0.474***	-0.465***	0.784***	0.076
AD	-0.409***	**1**	-0.147*	-0.244**	-0.210*	0.269**	-0.364***	0.019
ASI	-0.060	-0.182*	**1**	-0.006	-0.022	0.019	-0.008	-0.062
PH	0.227**	-0.175*	-0.021	**1**	0.193*	-0.164*	0.219**	-0.009
EPP	0.433***	-0.165*	-0.033	0.122	**1**	-0.075	0.021	0.071
EA	-0.339***	0.208	-0.011	-0.122	-0.023	**1**	-0.493***	-0.205**
NGPE	0.735***	-0.304**	-0.016	0.215**	-0.029	-0.426***	**1**	-0.141*
W100G	-0.003	-0.014	-0.060	-0.089	-0.039	0.178*	-0.312***	**1**

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant^{-1}; **NGPE** = number of grains ear^{-1}; **W100G** = weight of 100 grains; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EA** = ear aspect.

Correlation coefficients between GY and ASI were also negative but only significant under RDS ($p < 0.001$). Plant heights were positively and significantly correlated with GY under MHDS ($p < 0.001$) and non-stressed ($p < 0.01$) conditions but phenotypic correlation under SHDS was significant ($p < 0.001$) and negative whilst genotypic correlation was not significant ($p > 0.05$). Highly significant negative correlations were obtained under all environments with EA except phenotypic correlation under SHDS ($p > 0.05$).

Table 5-3b shows the results from partitioning the correlation coefficients obtained in the inbreds *per se* trial into direct and indirect effects following path coefficient analyses. It was observed that, under SHDS, ear aspect (EA) had the highest direct (diagonal) path coefficient (-0.559) followed by EPP (0.365) and ASI (-0.119). Among the secondary traits, the coefficients between AD - EA (-0.200) and EPP – EA (0.162) were the two highest. In total, EA (-0.659), EPP (0.548) and AD (-0.181) had the three highest effects on GY under SHDS. In the MHDS environments the highest direct effect was produced by EA (0.470) followed by ASI (0.414), while EPP showed the highest indirect effect through EA (-0.117) and AD through EA (0.022). The highest total effects in the MHDS environment were due to EA (0.478), ASI (0.401) and EPP (-0.234).

Highest direct effects under RDS were produced by NGPE (-1.031), EPP (0.192) and ASI (-0.110). Indirectly, EA contributed more through NGPE (0.465) followed by ASI through NGPE (0.441) and NGPE through W100G (0.314). In total, NGPE (0.756), ASI (-0.542), EA (-0.466) and EPP (0.421) contributed more for GY. Highest direct path coefficient under non-stressed condition was observed on NGPE (-0.431). This trait had also the highest indirect path coefficients EA (0.212) and AD (0.157), and the highest total effect on GY (0.784). On the total effect, EPP, EA and AD also had relatively high coefficients (0.474, -0.465 and -0.422, respectively).

Hybrids: In the diallel cross hybrids trial (Table 5-4a), both phenotypic and genotypic correlations of GY with EPP were positive and significant apart from the heat stress (HS) environment where $p > 0.05$ for genotypic correlation coefficient. Genotypic correlations for GY and plant height (PH) were highly significant ($p < 0.001$) individual stresses and non-stressed conditions but not significant under combined heat and drought stress (CHDS). Phenotypic correlations were also significant at $p < 0.001$ under drought alone and non-stressed conditions but not significant under heat alone and CHDS. With NGPE, both phenotypic and genotypic correlations were highly significant ($p < 0.001$) under individual stresses and non-stressed environments while with W100G only the phenotypic coefficients

under individual stresses were statistically significant ($p < 0.001$ under heat and $p < 0.01$ under drought).

Table 5-3b. Direct (path coefficients on diagonals), indirect (below and above diagonals) and total (right end column) effects of maize traits on grain yield of 108 inbreds evaluated in four different environments.

Severe heat-drought stress (SHDS) – Chiredzi 2014 hot and off-rain, managed drought

	AD	ASI	PH	EPP	EA	Total effect on GY
AD	**-0.040**	0.053	0.004	-0.059	**-0.200**	-0.181
ASI	0.018	**-0.119**	-0.001	-0.024	0.019	-0.122
PH	-0.003	0.003	**0.052**	0.020	0.098	0.156
EPP	0.006	0.008	0.003	**0.365**	**0.162**	**0.548**
EA	-0.014	0.004	-0.009	**-0.106**	**-0.559**	**-0.659**

Moderate heat-drought stress (MHDS) – Save Valley 2014 hot and off-rain, managed drought

	AD	ASI	PH	EPP	EA	Total effect on GY
AD	**-0.094**	-0.031	-0.006	-0.006	**0.022**	-0.119
ASI	0.007	**0.414**	-0.004	0.010	0.008	**0.401**
PH	-0.009	0.029	**-0.059**	-0.007	-0.074	-0.153
EPP	-0.013	-0.085	-0.009	**-0.047**	**-0.117**	**-0.234**
EA	-0.004	0.007	0.023	0.012	**0.470**	**0.478**

Random drought stress (RDS) – Chókwè 2014/15, rainfed

	AD	ASI	PH	EPP	EA	NGPE	W100G	Total effect on GY
AD	**-0.064**	-0.009	-	-0.040	-0.003	0.263	-0.003	**-0.364**
ASI	-0.005	**-0.110**	-	-0.035	-0.004	**0.441**	-0.003	**-0.542**
EPP	0.014	0.020	-	**0.192**	0.002	0.079	-0.003	**0.421**
EA	-0.012	-0.026	-	-0.025	**-0.016**	**0.465**	-0.002	**-0.466**
NGPE	0.016	0.047	-	-0.015	0.007	**-1.031**	0.026	**0.756**
W100G	-0.002	-0.004	-	0.008	-0.0004	**0.314**	**-0.085**	-0.029

Non-stressed – Chókwè 2014/15, fully-irrigated

	AD	ASI	PH	EPP	EA	NGPE	W100G	Total effect on GY
AD	**-0.087**	0.004	-0.006	-0.011	-0.002	**0.157**	0.001	**-0.422**
ASI	0.013	**-0.030**	-0.0001	-0.001	-0.0002	0.004	-0.004	-0.057
PH	0.021	0.0002	**0.025**	0.010	0.001	-0.094	-0.0005	**0.262**
EPP	0.018	0.0007	0.005	**0.0540**	0.0007	-0.009	0.004	**0.474**
EA	-0.024	-0.0006	-0.004	-0.004	**-0.009**	**0.212**	-0.012	**-0.465**
NGPE	0.032	0.0002	0.005	0.001	0.004	**-0.431**	-0.008	**0.784**
W100G	-0.002	0.0018	-0.0002	0.004	0.002	0.061	**0.059**	0.076

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant^{-1}; **NGPE** = number of grains ear^{-1}; **W100G** = weight of 100 grains; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EA** = ear aspect.

Table 5-4a. Phenotypic (below diagonals) and genotypic (above diagonals) correlation coefficients among maize traits of 45 diallel single crosses evaluated in four different environments.

Moderate heat-drought stress (MHDS) – Chókwè, 2014 hot and off-rain, managed drought

	GYG	AD	ASI	PH	EPP	EA	PA
GYG	**1**	-0.1155	-0.312***	-0.06455	0.302**	-0.545***	-0.394***
AD	-0.173*	**1**	-0.028	0.643***	-0.220**	0.041	-0.255**
ASI	-0.054	-0.020	**1**	-0.11784	0.150	0.390***	0.265**
PH	0.075	0.387***	-0.025	**1**	-0.235**	-0.060	-0.328***
EPP	0.269**	-0.155	0.030	-0.00233	**1**	-0.063	0.022
EA	-0.524***	0.049	0.111	-0.06278	-0.117	**1**	0.270
PA	-0.441***	-0.002	0.198*	-0.253**	-0.110	0.293**	**1**

Isolated heat stress (HIS) – Chókwè, 2014 hot and off-rain, fully-irrigated

	GYG	AD	ASI	PH	EPP	NGPE	W100G
GYG	**1**	0.180*	0.002	0.498***	0.032	0.580***	0.250**
AD	-0.184*	**1**	-0.034	0.385***	-0.069	0.073	0.257**
ASI	-0.127	0.100	**1**	-0.077	-0.217**	-0.226**	-0.022
PH	0.020	0.415***	0.046	**1**	-0.012	0.451***	0.038
EPP	0.204*	-0.168	0.008	-0.007	**1**	-0.228**	-0.147
NGPE	0.846***	-0.120	-0.104	0.008	-0.154	**1**	-0.114
W100G	0.316***	0.140	0.165	0.194*	0.022	0.126	**1**

Isolated drought stress (IDS) – Chókwè 2015 off-rain, managed drought

	GYG	AD	ASI	PH	EPP	EA	NGPE	W110G
GYG	**1**	0.076	0.162	0.313***	0.468***	-0.375***	0.842***	0.089
AD	-0.034	**1**	0.457***	0.626***	0.073	0.018	0.107	-0.054
ASI	-0.153	0.392***	**1**	0.444***	0.277**	0.056	0.267**	-0.300**
PH	0.566***	0.058	-0.264**	**1**	0.258**	-0.133	0.278**	-0.105
EPP	0.565***	-0.033	-0.101	0.378***	**1**	-0.338***	0.279**	-0.229**
EA	-0.558***	0.151	0.342***	-0.598***	-0.500***	**1**	-0.355***	0.033
PA	-	-	-	-	-	-	-	-
NGPE	0.716***	0.068	0.066	0.334***	0.216**	-0.347***	**1**	-0.303**
W110G	0.217**	-0.073	-0.315***	0.260**	0.029	-0.207*	-0.291**	**1**

Unstressed – Chókwè 2015, fully-irrigated

	GYG	AD	ASI	PH	EPP	EA	PA	NGPE	W100G
GYG	**1**	0.273**	0.018	0.396***	0.320***	-0.488***	-0.485***	0.537***	0.092
AD	0.179*	**1**	0.179*	0.574***	0.283**	0.011	-0.461***	0.289**	-0.426***
ASI	0.026	-0.046	**1**	0.142	-0.099	0.159	-0.007	0.223**	-0.229**
PH	0.341***	0.343***	-0.0003	**1**	0.205*	-0.180*	-0.504***	0.358***	-0.249**
EPP	0.217**	0.181*	-0.025	0.063	**1**	-0.046	-0.283**	0.069	-0.218**
EA	-0.362***	0.044	0.038	-0.193	-0.021	**1**	0.456***	-0.43721	-0.011
PA	-0.501***	-0.157	-0.056	-0.397	-0.110	0.519***	**1**	-0.403***	0.247**
NGPE	0.430***	0.127	0.089	0.221	-0.070	-0.244**	-0.286**	**1**	-0.514***
W100G	0.153	-0.159	-0.095	-0.038	-0.089	-0.176*	-0.093	-0.474***	**1**

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant^{-1}; **NGPE** = number of grains ear^{-1}; **W100G** = weight of 100 grains; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EA** = ear aspect.

Genetic correlations between GY and AD were significant at $p < 0.05$ under heat stress alone and at $p < 0.01$ under non-stressed environment but not under MHDS and drought

stress alone. Phenotypic coefficients were significant at $p < 0.05$ under MHDS, heat stress alone and unstressed environments but not under drought stress alone. Both genotypic and phenotypic correlation coefficients between grain yield and ASI were not significant under all environments except genotypic correlation under CHDS ($p < 0.001$).

Plant heights were not correlated with GY under CHDS ($p > 0.05$) and only the genotypic coefficient was significant under HS ($p < 0.001$). Same level of significance ($p < 0.001$) was observed for phenotypic correlations with PH under DS and non-stressed environments, while the genotypic correlation coefficient was significant at $p < 0.05$ under DS and at $p < 0.01$ under non-stressed conditions. With EA and PA (plant aspect), highly significant ($p < 0.001$) and negative (which correspond to positive in the case of EA and PA) correlation coefficients (both phenotypic and genotypic) were observed under the environments where the traits were assessed.

Path coefficient analyses of hybrid trial data (Table 5-4b) under CHDS revealed that ASI was the only trait with high direct (diagonal) effect on GY (-0.108). Highest indirect coefficient was between AD – PH (-0.058), followed by PH – PA (0.027), PH – EPP (0.021), ASI – EA (-0.027), and ASI – PA (-0.022). For total effect, EA (-0.545) had the highest values under CHDS followed by PA (-0.394), ASI (-0.312) and EPP (0.302). Under HS, the highest value of direct effects on GY was estimate for NGPE (1.063), followed by W100G (0.431), ASI (0.223), PH (0.183) and EPP (0.132). Highest indirect effects were estimated between [PH – NGPE (0.138)], followed by [EPP – NGPE (-0.070) - W100G (-0.029)], [ASI – NGPE (-0.069)], [AD – W100G (0.050)] and [NGPE – W100G (-0.035)]. Total effects under HS were highest for NGPE (1.514), followed by PH (0.560), W100G (0.274) and EPP (0.250).

Under DS only EPP and NGPE had relatively high estimates of direct effects (0.197 and 0.100, respectively). The indirect effects were highest between [PH – EPP (0.074)], followed by [PH – NGPE (0.033) - EPP (0.022) - EA (-0.098)], [EPP – NGPE (0.022)], [EA – NGPE (-0.035)] and [W100G - NGPE (-0.029)]. The total effects under DS were highest for NGPE, followed by EA, PH, and EPP (0.716, -0.558, 0.566 and 0.565, respectively). Finally, under the non-stressed environment for the diallel hybrids, W100G AD and EA had the three highest direct effects of 0.457, 0.197 and -0.133, respectively. Seven indirect paths were identified and among these, six were linked to W100G. These were [NGPE – W100G], [AD – W100G], [PH – W100G], [PA – W100G], [ASI – W100G] and [EPP – W100G] with indirect coefficients of -0.235, -0.195, -0.114, 0.113, -0.105 and -0.100. The seventh indirect path was [AD – PH (0.113)]. Highest estimates for total effect under non-stressed environment was for NGPE (0.537) followed by EA (-0.488) and PA (-0.485), PH (0.396), EPP (0.320), and AD (0.273).

Table 5-4b. Direct (path coefficients on diagonals), indirect (bellow and above diagonals) and total (right end column) effects of maize traits on grain yield of 45 diallel single crosses evaluated in four different environments.

Moderate heat-drought stress (MHDS) – Chókwè, 2014 hot and off-rain, managed drought

	AD	ASI	PH	EPP	EA	PA	Total effect on GY
AD	**0.003**	0.003	**-0.058**	0.014	-0.003	**0.021**	-0.116
ASI	-0.00008	**-0.108**	0.011	-0.010	**-0.027**	**-0.022**	**-0.312**
PH	0.002	-0.013	**-0.091**	-0.015	0.004	**0.027**	0.065
EPP	-0.0006	-0.016	**0.021**	**-0.066**	0.004	-0.002	**0.302**
EA	0.0001	**-0.042**	0.005	0.004	**-0.068**	**-0.022**	**-0.545**
PA	-0.001	-0.029	0.030	-0.001	-0.018	**-0.083**	**-0.394**

Heat stress (HS) – Chókwè, 2014 hot and off-rain, fully-irrigated

	AD	ASI	PH	EPP	NGPE	W100G	Total effect on GY
AD	**-0.018**	-0.008	-0.0003	0.002	**0.022**	0.050	0.057
ASI	0.001	**0.223**	0.00005	0.006	**-0.069**	-0.004	-0.012
PH	-0.012	0.004	**0.183**	0.0003	**0.138**	0.007	**0.560**
EPP	0.002	0.011	0.000	**0.132**	**-0.070**	**-0.029**	**0.250**
NGPE	-0.002	0.012	-0.0003	0.006	**1.063**	-0.022	**1.514**
W100G	-0.008	0.001	-0.00003	0.004	**-0.035**	**0.431**	0.274

Drought stress (DS) – Chókwè 2015 off-rain, managed drought

	AD	ASI	PH	EPP	EA	NGPE	W110G	Total effect on GY
AD	**-0.046**	-0.002	0.005	-0.007	0.006	0.007	-0.002	-0.034
ASI	-0.018	**-0.004**	-0.025	-0.020	0.013	0.007	-0.007	-0.153
PH	-0.003	0.001	**0.095**	**0.074**	**-0.022**	**0.033**	0.006	**0.566**
EPP	0.002	0.0004	0.036	**0.197**	**-0.018**	**0.022**	0.0006	**0.565**
EA	-0.007	-0.001	-0.057	**-0.098**	**0.037**	-0.035	-0.004	**-0.558**
NGPE	-0.003	-0.0003	0.032	**0.042**	-0.013	**0.100**	-0.006	**0.716**
W110G	0.003	0.001	0.025	0.006	-0.008	-0.029	**0.022**	**0.217**

Non-stressed – Chókwè 2015, fully-irrigated

	AD	ASI	PH	EPP	EA	PA	NGPE	W100G	Total effect on GY
AD	**0.197**	0.003	0.052	0.018	-0.001	0.035	-0.023	**-0.195**	**0.273**
ASI	0.035	**0.018**	0.013	-0.006	-0.021	0.0005	-0.018	**-0.105**	0.018
PH	**0.113**	0.003	**0.090**	0.013	0.024	0.038	-0.028	**-0.114**	**0.396**
EPP	0.056	-0.002	0.018	**0.062**	0.006	0.021	-0.005	**-0.100**	**0.320**
EA	0.002	0.003	-0.016	-0.003	**-0.133**	-0.034	0.035	-0.005	**-0.488**
PA	-0.091	-0.0001	-0.045	-0.018	-0.061	**-0.075**	0.032	**0.113**	**-0.485**
NGPE	0.057	0.004	0.032	0.004	0.058	0.030	**-0.079**	**-0.235**	**0.537**
W100G	-0.084	-0.004	-0.022	-0.014	0.001	-0.019	0.041	**0.457**	0.092

*** = significant at probability of 0.1%; ** = significant at 1%; * = significant at 5%; ns = not statistically significant (p > 5%).

GY = grain yield; **EPP** = ears plant^{-1}; **NGPE** = number of grains ear^{-1}; **W100G** = weight of 100 grains; **AD** = days to anthesis; **ASI** = anthesis-silking interval; **PH** = plant height; **EA** = ear aspect.

5.4 Discussion

The traits considered in this study were chosen based on their relevance in the final expression of the main trait, grain yield (GY). Grain yield per area is a product of plant density, average number of ears plant^{-1} (EPP) number of grains ear^{-1} (NGPE) and average grain weight (GW): GY = NP × EPP × NGPE ×GW (Bänziger et al., 2000). However, NP is more affected during the early stages and very little genetic variability has been observed for this trait (Araus and Sanchez, 2012). Number of ears plant^{-1} and anthesis-silking interval (ASI) were validated by Mhike et al. (2012) as the most important traits under drought stress conditions. Ear and plant aspects (EA and PA, respectively) and plant height (PH) were also identified by Badu-Apraku et al. (2012) as the most reliable secondary traits for selection under drought stress conditions.

The significant inbred line *per se* variations for grain yield (GY) and other traits detected under the four experimental conditions, except plant height (PH) under severe heat-drought stress, are important indicators of possible selection progress for the target environments of this study (combined heat-drought stressed conditions). Most important, the suggested attainable progress can be translated into physical final products (hybrids) because ANOVA revealed highly significant diallel cross variations for GY and most of secondary traits under all environments where the hybrids were tested, including combined stress (Table 5-2), except EPP under CHDS, HS alone and non-stressed environment, and ASI under heat alone and non-stressed conditions.

The observed significant positive genotypic correlations between GY and EPP in inbred lines could be attributed to their own direct effects under SHDS and RDS, but indirectly through EA under MHDS. In hybrids, EPP contributed directly to GY under HS and DS, but indirectly through PH under combined heat-drought stress and through W100G under non-stressed condition. The correlation and path coefficients estimated for EA and PA were multiplied by "-1" for their proper interpretation because the best aspect was scored as "1" while the worst was attributed a value of "5. The significant correlations between EA and GY in inbred lines were due to direct effects under SHDS and MHDS but also indirectly under MHDS, through EPP, and under RDS and non-stressed environments through NGPE. In hybrids, EA mostly contributed indirectly under CHDS and DS conditions. The significant correlation coefficients between GY and PA, which was observed in the hybrids' trial, could only be attributed to indirect effects through PH under CHDS and through W100G under non-stressed conditions. The result suggests that GY under combined heat-drought stress can be rapidly improved by selecting phenotypically attractive genotypes with good ears aspect. The significant relationships between GY and EPP, PA and EA observed under different stresses of the

present study are similar to those reported by Badu-Apraku et al. (2012) under drought alone and low nitrogen stress conditions, and Mhike et al. (2012) for EPP under drought alone.

Correlation studies involving both NGPE and W100G are very rare. In this study, genotypic correlation coefficients between GY and W100G were not statistically significant in both inbred and hybrid trial under all environments except under RDS for inbred lines. Contribution of W100G to the inbreds' GY was indirect through NGPE under RDS. In hybrids, the significant phenotypic correlation observed between GY and W100G under individual stresses could be attributed to direct effect and also to indirect effects through NGPE, EPP and AD under HS. Under DS, W100G contributed to GY only indirectly through NGPE. In fact, in most cases, W100G showed significant correlation only with NGPE. It was because NGPE always exhibited significant and strong correlation with GY, with high direct effects, that W100G found paths to influence GY. Indirect effects of W100G have also been reported by Pavan et al. (2011) and Kumar et al. (2015). In the studies of Pavan et al. (2011) and Kumar et al. (2015), NGPE was partitioned into number of kernel rows ear^{-1} and number of kernels row^{-1} had high direct effects on GY.

Non-significant phenotypic and genotypic correlation coefficients between GY and ASI in inbred trial under all testing environments, except RDS, and in hybrid trial under all testing environments, except genotypic correlation under CHDS, indicate that the ASI did not determine GY in this study, contrary to what was reported by other researchers (Badu-Apraku, 2007; Bänziger et al., 2000; Betrán et al., 2003; Mhike et al., 2012). This apparent disagreement could be explained by the fact that the two trials had genotypes with very large flowering differences. Therefore, a genotype with very large ASI could still be successfully pollinated by the other surrounding genotypes in the trials of this study and other experiments nearby.

Path coefficient results on ASI were inconsistent across environments in the two trials. In the inbred trial, large ASI appeared to have directly reduced GY under SHDS and RDS environments as their direct coefficient effects were negative. In contrast, large ASI appeared to have contributed positively to GY under MHDS, while under non-stressed environment it did not show any effect. In the hybrid trial, the results suggest that GY was directly reduced by ASI under CHDS but under DS alone had a positive contribution.

Although the observed inconsistence of the path coefficient results on effects of large ASI to GY in different types of germplasm (inbred lines versus hybrids), the path coefficient analysis seem to have removed the apparent disagreement exposed by the non-significant phenotypic and genotypic correlation coefficients between the two traits. Based on the path

coefficient results it was clear that, under severe stress conditions, large ASI values were associated with reduced GY values in both inbred and hybrid trials. The results show that when severe stress growing conditions are targeted, selections must favour reduced ASI. This is because silks would catch up with the reduced period of pollen shedding that is normally observed under severe stress environments. Under less stressed environments ASI is not very important because the period of pollen shedding is generally long, especially when the tassel is big with many branches. These results are in agreement with the findings of (Mhike et al., 2012).

5.5 Conclusion

In general, number of ears plant^{-1} and number of grains ear^{-1} were the most important yield components that had positive direct contribution to grain yield of inbred lines and their hybrids under stressed and non-stressed conditions of this study. Therefore, EPP and NGPE can be successfully employed in breeding for combined heat and drought stress tolerance as well as for high yield potential.

Ear aspect was found to be important and consistent in both inbred lines and hybrids as a secondary trait contributing positively increased grain yield under stressed and non-stressed conditions.

Shorter anthesis-silking intervals would be important for improved grain yield under severe combined stress than under individual and moderate stress or non-stressed conditions, especially if pollen shedding window is narrow.

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Overview of the research findings

Introduction

This research was designed to conduct comparative genetic studies on tropical maize germplasm under different levels of heat and drought stress conditions. This chapter aims to make an overview of the study by summarising the key objectives and highlighting the most important findings. The implications of the major findings are also discussed.

The specific objectives of the study, which in turn were developed in research chapters, were the following:

1. to assess genetic variability for combined heat-drought stress tolerance in the available maize germplasm in Mozambique;
2. to study gene action controlling maize (*Zea mays* L.) grain yield and other agronomic traits under heat alone, drought alone and combined heat and drought stress conditions;
3. to determine the heterotic orientation of thirty selected maize inbred lines towards three drought-tolerant and one high yield potential males; and
4. to investigate the level of relationship between maize traits correlated with grain yield in inbred lines per se versus hybrids under stressed and non-stressed conditions.

Major findings

Genetic variability for combined heat-drought stress tolerance in tropical maize germplasm

- Genetic variability for combined heat-drought stress tolerance is wide among maize inbred lines available in Mozambique.
    - This was revealed by the genotypic differences observed under severe and moderate combinations of heat and drought stresses achieved in two environments of this research.
- Superior lines under severe combination of heat and drought stress versus the rest of the growing conditions of this study were not exactly the same.

- AMMI analysis identified four inbred lines that were among the top 10 under the three stressed environmental conditions of this study. These were the entries 16, 92, 107 and 108.
- GGE-biplot of genotypic wining was used and it identified two mega-environments with clear wining genotypes at each mega-environment.

- However, using average grain yield rank and geometric mean productivity index, 15 out of 108 inbred lines (14%) were identified as the most promising genotypes under stressful as well as under unstressed environments.

Gene action controlling maize grain yield and other agronomic traits under combined heat-drought stress conditions

- Both general and specific combining ability effects (GCA and SCA, respectively) were important in the expression of grain yield and all yield components, except number of ears plant^{-1}, indicating important role of additive and non-additive gene actions under the four individual environments:
  - General combining ability effects were generally predominant;
  - Degree of predominance of the GCA over SCA effects increased from the individual stresses to combined heat and drought stress conditions.
- For the other traits evaluated, GCA effects were clearly predominant over SCA effects regardless the stress category,
  - Only exception from husk cover for which the two categories of genetic effects were equally important.

Heterotic orientation of thirty maize inbred lines under fully-irrigated versus combined heat-drought stress conditions

- The four testers effectively discriminated the thirty inbred lines:
  - N3 was the best discriminator under favourable conditions.
  - CML312 and CML444 were better discriminators under stressed conditions.
- Heterotic orientation changed significantly with change in environmental conditions:
  - Twenty inbred lines (67%), including eight best GCA combiners, changed from one tester to another when experimental conditions changed from fully-irrigated to random and moderate drought stress.
  - Only seven female lines did not change. These were TCL10, TCL12, TCL24, TCL28, TCL36, TC37 and TC41.

- Apart from maintaining their heterotic orientation under different environmental conditions, Female lines TCL28 and TCL36 have got the second and third best GCA effect estimates for grain yield; therefore they are good parents for future breeding programmes.

Correlation and path coefficient analysis of maize grain yield with other characteristics under fully-irrigated versus water-limited conditions

- Number of ears plant^{-1} and number of grains ear^{-1} were the most important yield components that had positive direct contribution to grain yield of inbred lines and their hybrids counterparties under stressed and non-stressed conditions of this study.
- Ear aspect was found to be very important and consistent in both inbred lines and hybrids as a non-yield component secondary trait contributing positively for increased grain yield under stressed and non-stressed conditions.
- Importance of anthesis-silking intervals on influencing grain yield was more under severe combined stress than under isolated and moderate stress or non-stressed conditions.

Implication of the findings in the practical breeding programmes

Heat and drought stresses occur simultaneously during the main cropping seasons in many tropical environments, causing frequent crop failures, especially maize. This has raised serious concern among farmers and public leadership, and triggered exciting debates among scientists during the recent years. Plant breeders are faced with the challenge of meeting the crop needs of future generations taking in account both population growth and climate change. From the crop improvement perspective, development of varieties with increased resilience to tropical/subtropical hot and water-limited environments would be a better strategy to address the challenge.

The existence of genetic variability for combined heat and drought stress in tropical maize germplasm revealed by this study is a good result as selection can be successful only if there is genetic variation in the available germplasm. The superior genotypes across environments can be employed in future breeding programmes.

The observed importance of both additive and non-additive gene actions, with increased predominance of the additive type under stressful environments, is an exciting finding for maize breeding that address combined heat and drought stress. Combined with their high

heritability estimate relative to grain yield, the confirmed significant correlation of number of ear plant^{-1} as well as plant and ear aspects is very important in speeding up the breeding progress for combined stress environments.

Breeding for stressful environments shall be careful to not result in genetic erosion for high yielding potential. The need for using appropriate testers under favourable versus stressed environment was indicated in this research by identifying N3 as the best genotypic discriminator under non-stressed and CML312 and CML444 as better under stressed environments.

Screening for multiple-stress tolerance is a tedious and expensive activity and there is need to narrow down the target secondary traits. The stronger relationship between grain yield and average number of ears per pant, ear aspect, anthesis-silking interval and number of grains per ear under both stressed and non-stressed environmental conditions, revealed by the path coefficient analysis, allows recommending only these four secondary traits to the breeders screening maize for combined heat and drought stress tolerance.

Appendices

Appendices from chapter 2

Appendix 2-1. 108 experimental maize inbred lines from four sources

Entry	Code	Inbred line	Origin
1	IL-1	ZM421-2-1-2-1-1-1-2-B*3-B	IIAM-Mozambique
2	IL-2	ZM421-2-1-2-1-1-5-1-1-B	IIAM-Mozambique
3	IL-3	ZM421-2-1-2-1-1-5-2-1-B	IIAM-Mozambique
4	IL-4	ZM421-2-1-2-1-2-2-1-B*2-B	IIAM-Mozambique
5	IL-5	ZM421-6-4-1-2-2-2-2-B	IIAM-Mozambique
6	IL-6	ZM421-7-2-1-1-4-3-1-1-B	IIAM-Mozambique
7	IL-7	ZM421-7-2-1-1-4-3-1-2-B	IIAM-Mozambique
8	IL-8	ZM421-7-old	IIAM-Mozambique
9	IL-9	ZM421-9-3-2-3-1-1-B*2-B	IIAM-Mozambique
10	IL-10	ZM421-12-1-1-2-2-1-6-1-B	IIAM-Mozambique
11	IL-11	ZM421-12-1-1-2-2-1-8-1-B	IIAM-Mozambique
12	IL-12	ZM421-12-1-1-2-2-2-1-1-B	IIAM-Mozambique
13	IL-13	ZM421-12-2-3-4-1-1-2-1-B	IIAM-Mozambique
14	IL-14	ZM421-12-3-3-1-1-1-1-B	IIAM-Mozambique
15	IL-15	ZM421-12-3-3-1-3-2-1-B	IIAM-Mozambique
16	IL-16	ZM421-12-3-3-1-4-1-1-B	IIAM-Mozambique
17	1L-17	ZM421-12-old	IIAM-Mozambique
18	IL-18	ZM421-16-1-1-2-1-1-1-1-B	IIAM-Mozambique
19	IL-19	ZM421-16-1-1-2-1-1-1-3-B	IIAM-Mozambique
20	IL-20	ZM421-18-8-1-3-1-3-1-3-B	IIAM-Mozambique
21	IL-21	ZM421-20-1-1-5-1-2-1-B	IIAM-Mozambique
22	IL-22	ZM421-22-2-2-1-2-1-4-B*2-B	IIAM-Mozambique
23	IL-23	ZM421-29-2-1-1-1-4-1-B	IIAM-Mozambique
24	IL-24	ZM421-40-1-2-2-3-4-1-B	IIAM-Mozambique
25	IL-25	ZM421-72-1-1-3-2-3-1-B	IIAM-Mozambique
26	IL-26	ZM421-72-1-1-3-3-1-1-B	IIAM-Mozambique
27	IL-27	ZM421-77-1-3-2-3-1-1-B	IIAM-Mozambique
28	IL-28	ZM421-77-1-3-2-3-1-2-B	IIAM-Mozambique
29	IL-29	ZM521-10-1-1-2-2-1-2-1-B	IIAM-Mozambique
30	IL-30	ZM521-12-1-1-4-2-2-5-1-B	IIAM-Mozambique
31	IL-31	ZM521-13-3-2-3-1-1-B*2-B	IIAM-Mozambique
32	IL-32	ZM521-13-3-2-3-1-2-2-B	IIAM-Mozambique
33	IL-33	ZM521-15F-old	IIAM-Mozambique
34	IL-34	ZM521-20-1-1-2-2-2-2-B	IIAM-Mozambique
35	IL-35	ZM521-29-2-1-1-1-2-5-B	IIAM-Mozambique
36	IL-36	ZM521-29-2-1-2-1-1-2-1-B	IIAM-Mozambique
37	IL-37	ZM521-29-2-1-5-2-1-2-1-B	IIAM-Mozambique
38	IL-38	ZM521-38-2-3-1-1-3-1-1-B	IIAM-Mozambique
39	IL-39	ZM521-38-3-1-2-1-1-1-B	IIAM-Mozambique
40	IL-40	ZM521-40-1-3-1-1-3-B*3-B	IIAM-Mozambique
41	IL-41	ZM521-40-1-3-1-1-5-B*2-B	IIAM-Mozambique
42	IL-42	ZM521-40-1-3-1-2-2-1-B	IIAM-Mozambique
43	IL-43	ZM521-42-2-1-2-1-2-1-B	IIAM-Mozambique
44	IL-44	ZM521-8-4-2-3-1-2-1-B	IIAM-Mozambique
45	IL-45	ZM621-19-4-2-1-1-1-1-1-B	IIAM-Mozambique
46	IL-46	ZM621-19-4-2-1-1-1-2-1-B	IIAM-Mozambique
47	IL-47	ZM621-24-3-1-1-1-1-1-1-B	IIAM-Mozambique

Entry	Code	Inbred line	Origin
48	IL-48	ZM621-24-3-1-1-1-1-3-1-B	IIAM-Mozambique
49	IL-49	INTBC1F2FS-13-2-1-4-1-1-2-2-B	IIAM-Mozambique
50	IL-50	INTBC1F2FS-19-2-2-1-1-1-1-1-B	IIAM-Mozambique
51	IL-51	INTBC1F2FS-27-1-3-2-1-1-1-1-B	IIAM-Mozambique
52	IL-52	INTBC1F2FS-27-1-3-2-1-2-1-1-B	IIAM-Mozambique
53	IL-53	MATUBASG-14-1-4-3-3-1-9-5-B	IIAM-Mozambique
54	IL-54	MATUBASG-26-1-3-3-1-1-4-2-B	IIAM-Mozambique
55	IL-55	MATUBASG-26-1-3-3-1-1-6-1-B	IIAM-Mozambique
56	IL-56	MATUBASG-26-1-3-3-1-2-4-1-B	IIAM-Mozambique
57	IL-57	MATUBASG-26-1-3-3-1-2-5-1-B	IIAM-Mozambique
58	IL-58	MATUBASG-26-1-3-3-1-2-6-1-B	IIAM-Mozambique
59	IL-59	P501SRC0/P502SRC0-26-1-1-1-2-1-1-1-B	IIAM-Mozambique
60	IL-60	P501SRC0/P502SRC0-26-1-1-1-2-3-1-B*2-B	IIAM-Mozambique
61	IL-61	P501SRC0/P502SRC0-31-1-3-1-2-3-1-1-B	IIAM-Mozambique
62	IL-62	SUWAN8075DMR-79-2-1-2-2-B-B-2	IIAM-Mozambique
63	IL-63	SUWAN8075DMR-64-1-1-1-1-1-1-2-B	IIAM-Mozambique
64	IL-64	SYNSYNF1FS-16-1-2-4-2-1-2-1-B	IIAM-Mozambique
65	IL-65	SYNSYNF1FS-16-1-2-4-2-2-1-1-B	IIAM-Mozambique
66	IL-66	TSEGRIM-3-1-5-1-1-1-1-1-B	IIAM-Mozambique
67	IL-67	TSEGRIM-3-1-5-1-1-1-5-2-B	IIAM-Mozambique
68	IL-68	TSEGRIM-3-1-5-2-1-1-3-1-B	IIAM-Mozambique
69	IL-69	DMR15	IIAM-Mozambique
70	IL-70	DRA-S4-2-1-1-B	IIAM-Mozambique
71	IL-71	CHINACAFS-7-2-1-2-1-2-B	IIAM-Mozambique
72	IL-72	CHINACAFS-43-3-1-1-2-B	IIAM-Mozambique
73	IL-73	CHINACAFS-68-3-1-3-1-B	IIAM-Mozambique
74	IL-74	CHINACAFS-71-3-1-1-1-1-B	IIAM-Mozambique
75	IL-75	CHINACAFS-75-1-1-2-1-B	IIAM-Mozambique
76	IL-76	CHINACAFS-75-1-1-3-1-B	IIAM-Mozambique
77	IL-77	CHINACAFS-80-1-1-2-1-B	IIAM-Mozambique
78	IL-78	CHINACAFS-80-2-1-2-1-B	IIAM-Mozambique
79	IL-79	CHINACAFS-81-1-1-2-2-1-B-B	IIAM-Mozambique
80	IL-80	CHINACAFS-129-3-2-1-2-B	IIAM-Mozambique
81	IL-81	CHINACAFS-169-2-1-2-1-B*2-B	IIAM-Mozambique
82	IL-82	TSANGANOFS-25-1-2-1-1-1-B	IIAM-Mozambique
83	IL-83	CML395	CIMMYT
84	IL-84	CML443	CIMMYT
85	IL-85	CML444	CIMMYT
86	IL-86	CML445	CIMMYT
87	IL-87	CML489	CIMMYT
88	IL-88	CML537	CIMMYT
89	IL-89	CML539	CIMMYT
90	IL-90	CML547	CIMMYT
91	IL-91	CKL05017	CIMMYT
92	IL-92	CZL04007	CIMMYT
93	IL-93	CZL054	CIMMYT
94	IL-94	CZL068	CIMMYT
95	IL-95	ZEWAc1F2-300-2-2-B-1-B*5	CIMMYT
96	IL-96	NIP25-20-1-1-B-1-B	CIMMYT
97	IL-97	IRMA17	CIMMYT
98	IL-98	IRMA11	CIMMYT
99	IL-99	IRMA23	CIMMYT
100	IL-100	IRMA3	CIMMYT

Entry	Code	Inbred line	Origin
101	IL-101	IITA1	IITA
102	IL-102	IITA2	IITA
103	IL-103	LP19	IIAM-Mozambique
104	IL-104	LP21	IIAM-Mozambique
105	IL-105	LP23	IIAM-Mozambique
106	IL-106	LaPostaSeqC7-F18-3-2-1-1-B*9	CIMMYT
107	IL-107	DTPYC9-F46-1-2-1-1-B	CIMMYT
108	IL-108	DTPYC9-F46-1-2-1-2-B	CIMMYT

Appendix 2-2. Best linear unbiased estimated (BLUE) means for grain yield and other traits of 108 maize inbred lines evaluated at Chiredzi and Save Valley and Chókwè under two water-regimes.

(2-2.a) Chiredzi fully-irrigated under heat stress

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Ear	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Rot	Sen.	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
1	IL-1	1.13	19.82	74.1	1.4	171.0	0.49	2.2	6.7	0.77	22.5	5.4	3.0	16.8	3.5
2	IL-2	0.91	40.30	71.5	1.5	160.9	0.57	6.1	-0.6	0.58	9.6	6.4	3.3	15.2	3.4
3	IL-3	0.71	56.32	69.7	0.6	147.6	0.49	17.2	3.4	0.57	22.0	7.2	3.5	15.6	3.3
4	IL-4	0.68	60.47	68.8	2.6	129.8	0.56	6.1	6.9	0.66	24.2	6.6	3.1	16.5	3.7
5	IL-5	0.70	65.22	72.0	1.5	119.9	0.61	2.8	9.0	0.57	51.9	6.3	4.3	16.3	4.4
6	IL-6	0.57	72.87	70.8	1.4	126.8	0.40	3.6	5.8	0.70	50.1	5.7	4.1	15.1	3.8
7	IL-7	0.70	54.17	72.3	-1.5	129.5	0.53	0.1	6.6	0.60	51.4	5.8	3.8	12.9	3.6
8	IL-8	0.81	48.84	71.9	0.6	143.0	0.56	8.0	9.0	0.72	50.6	6.3	4.5	16.6	4.4
9	IL-9	0.62	69.62	72.6	2.4	168.0	0.56	28.6	0.0	0.47	61.2	5.9	4.8	14.9	3.8
10	IL-10	1.27	22.83	68.0	2.1	129.5	0.61	20.5	-0.2	0.79	23.1	7.0	2.8	16.0	3.1
11	IL-11	2.01	-9.70	71.0	0.4	171.7	0.53	22.3	0.5	0.86	15.9	5.9	2.8	16.0	3.0
12	IL-12	1.07	40.25	76.1	4.4	158.2	0.50	16.7	-0.1	0.57	59.0	6.6	4.2	15.1	4.2
13	IL-13	0.61	70.31	75.1	2.7	170.2	0.48	13.8	3.2	0.24	16.3	6.2	3.7	16.1	4.1
14	IL-14	0.33	101.94	78.0	1.1	140.3	0.62	-0.7	2.7	0.19	36.0	6.8	4.2	15.0	4.1
15	IL-15	0.71	71.29	69.0	5.5	144.9	0.52	18.0	18.1	0.59	25.8	7.6	3.5	15.4	3.6
16	IL-16	1.21	25.74	73.3	2.6	171.3	0.65	14.6	0.6	0.52	24.5	5.7	3.0	16.0	3.5
17	IL-17	1.25	12.29	70.8	1.5	167.5	0.58	1.3	-0.3	0.78	18.0	5.8	3.1	17.1	3.2
18	IL-18	0.37	96.20	68.6	0.6	131.9	0.55	18.6	12.3	0.66	30.9	7.3	4.3	15.0	4.2
19	IL-19	0.92	41.86	70.0	1.1	136.5	0.44	11.0	30.2	0.56	25.7	7.2	4.4	14.0	4.3
20	IL-20	0.65	67.38	72.6	3.3	132.8	0.58	25.3	-1.1	0.87	38.5	5.5	3.6	13.6	3.6
21	IL-21	0.96	34.72	72.6	0.0	161.9	0.52	11.8	8.1	0.79	36.4	6.5	3.3	16.8	3.5
22	IL-22	1.29	28.61	69.7	0.1	180.2	0.48	5.3	9.0	0.62	50.4	6.4	3.2	15.3	3.0
23	IL-23	0.63	66.63	70.8	2.5	162.5	0.50	4.0	1.5	0.63	79.2	5.8	5.0	15.9	4.1
24	IL-24	0.31	88.32	75.7	4.6	140.3	0.51	17.6	0.1	0.52	81.3	6.4	4.8	14.4	4.9
25	IL-25	0.88	46.17	73.7	0.6	147.0	0.43	1.0	3.5	0.73	33.9	6.3	3.7	16.3	3.9
26	IL-26	0.41	83.55	75.7	0.5	175.6	0.55	13.1	0.5	0.57	31.4	6.8	4.2	14.0	4.1

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Ear	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Rot	Sen.	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
27	IL-27	0.85	48.43	71.1	-0.5	147.5	0.59	16.2	-0.5	0.59	31.4	6.2	3.7	15.9	4.0
28	IL-28	0.59	66.49	74.3	2.0	147.9	0.38	3.1	3.8	0.54	51.7	5.8	4.0	13.3	4.2
29	IL-29	0.93	35.64	69.1	-0.5	129.6	0.52	1.6	2.9	0.78	11.1	7.9	3.6	15.1	3.7
30	IL-30	0.93	30.90	71.9	1.0	150.5	0.51	14.2	-0.2	0.69	51.2	5.9	4.0	15.9	3.9
31	IL-31	2.08	4.94	72.7	0.1	150.1	0.62	13.2	0.2	0.72	27.6	5.3	2.7	16.3	3.0
32	IL-32	0.55	72.19	69.5	5.5	136.8	0.50	22.5	0.2	0.53	37.4	6.2	3.9	15.4	4.1
33	IL-33	0.79	47.53	68.1	2.4	134.6	0.56	-2.2	-0.5	0.69	37.1	6.1	3.8	15.6	3.6
34	IL-34	0.78	53.87	71.4	4.2	151.4	0.47	-3.6	13.0	0.66	27.9	5.9	3.7	17.0	3.6
35	IL-35	0.70	56.39	72.1	2.5	137.2	0.44	20.8	-0.5	0.66	44.8	6.6	3.8	15.0	3.8
36	IL-36	0.72	55.52	72.8	3.5	134.3	0.42	-2.7	0.7	0.80	31.4	5.7	4.0	16.2	3.8
37	IL-37	0.87	55.55	68.1	0.5	121.3	0.55	16.0	0.7	0.52	50.5	7.2	3.4	15.0	4.1
38	IL-38	0.85	41.86	72.0	1.5	120.5	0.55	-4.3	-0.2	0.71	42.6	5.2	4.0	16.0	3.9
39	IL-39	0.39	93.04	77.1	3.6	151.2	0.61	2.2	-0.3	0.60	69.7	5.9	4.2	12.3	4.4
40	IL-40	0.48	85.81	72.2	4.5	133.1	0.52	2.4	6.3	0.75	33.2	5.9	3.9	15.3	3.9
41	IL-41	0.37	91.84	70.6	4.9	152.7	0.64	2.1	2.9	0.52	72.5	5.6	4.7	16.0	4.9
42	IL-42	0.98	28.88	73.2	0.3	138.9	0.51	0.4	6.6	0.73	20.8	6.1	3.6	14.5	3.5
43	IL-43	1.95	-1.03	70.6	0.5	172.1	0.60	-1.6	-0.9	0.53	21.4	6.7	2.9	15.5	3.0
44	IL-44	0.56	72.46	73.4	0.3	155.2	0.60	-0.3	16.4	0.55	28.9	6.3	3.5	15.5	3.8
45	IL-45	0.47	80.11	71.7	1.4	139.6	0.64	2.0	4.2	0.67	40.1	7.4	3.8	14.4	3.6
46	IL-46	1.07	31.49	68.4	-1.0	151.2	0.56	5.8	-0.3	0.71	23.3	6.6	3.6	17.0	3.8
47	IL-47	1.02	32.31	70.8	0.9	135.5	0.47	16.3	0.2	0.71	43.3	6.4	3.3	16.2	4.0
48	IL-48	0.65	64.73	75.9	2.5	160.4	0.57	-1.5	0.1	0.48	53.5	6.6	4.4	16.9	3.7
49	IL-49	0.84	45.23	67.5	3.0	128.2	0.57	4.2	5.1	0.70	14.1	6.7	3.3	17.1	3.6
50	IL-50	0.80	48.21	74.6	0.5	186.0	0.38	12.8	-0.1	0.72	55.9	6.4	4.0	15.8	3.9
51	IL-51	1.22	25.64	69.3	1.5	148.0	0.63	14.3	0.3	0.86	15.8	6.1	3.7	16.0	3.6
52	IL-52	0.47	85.85	74.7	0.1	141.5	0.56	22.0	5.3	0.68	56.8	6.1	4.2	10.5	4.3
53	IL-53	0.80	51.36	76.2	-0.5	137.6	0.57	13.0	9.1	0.39	31.9	5.9	3.2	16.9	3.5
54	IL-54	1.06	35.59	68.4	1.1	165.8	0.47	8.4	-0.4	0.71	47.3	6.3	3.7	16.6	4.1
55	IL-55	0.89	44.04	69.2	1.7	154.2	0.49	23.4	3.8	0.55	16.8	6.8	3.5	15.0	3.8
56	IL-56	0.47	79.70	75.2	0.6	164.9	0.47	-0.4	10.4	0.56	49.1	6.6	4.2	14.8	4.2

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Sen.	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
57	IL-57	0.42	85.28	75.0	2.2	134.9	0.57	-1.5	5.3	0.53	43.3	5.8	4.3	15.7	4.3
58	IL-58	0.48	82.39	70.8	0.7	141.1	0.55	13.0	0.4	0.39	31.2	7.0	3.7	14.7	4.0
59	IL-59	0.70	59.31	74.8	0.5	130.4	0.60	-2.4	10.0	0.58	41.9	6.3	3.6	16.5	3.4
60	IL-60	0.60	73.19	72.9	3.3	134.4	0.59	3.2	-0.7	0.61	33.2	6.5	4.4	16.5	4.4
61	IL-61	0.84	43.44	72.2	2.4	147.4	0.49	3.5	0.8	0.65	9.8	7.0	3.6	16.0	3.4
62	IL-62	0.63	65.91	77.6	3.3	141.2	0.54	-2.5	6.6	0.47	42.0	6.2	4.0	16.1	4.3
63	IL-63	0.63	72.46	72.1	3.9	138.8	0.49	14.4	-0.1	0.32	38.6	5.3	3.0	15.9	3.5
64	IL-64	1.14	24.68	66.4	0.6	161.1	0.57	45.7	-0.3	0.82	18.2	7.7	3.3	16.4	3.6
65	IL-65	0.97	37.21	70.4	3.5	180.7	0.43	13.8	0.1	0.54	41.4	7.3	3.7	16.4	4.0
66	IL-66	0.92	39.12	70.5	0.0	146.4	0.49	-1.1	-0.3	0.62	39.3	7.3	3.9	13.6	3.8
67	IL-67	0.61	71.89	74.2	-0.2	151.8	0.43	13.1	0.1	0.65	28.1	6.5	3.7	15.3	3.9
68	IL-68	0.35	86.40	71.1	5.7	135.4	0.47	20.0	0.3	0.54	43.7	6.5	3.9	12.7	3.9
69	IL-69	0.88	51.33	75.3	0.9	142.4	0.53	11.4	13.8	0.61	27.2	6.6	4.0	17.2	3.7
70	IL-70	0.76	50.02	72.0	1.5	132.3	0.58	2.5	0.1	0.93	35.8	5.9	4.2	14.8	4.2
71	IL-71	1.24	20.66	69.2	0.4	155.9	0.66	-1.7	5.4	0.73	34.9	6.7	3.3	16.4	3.8
72	IL-72	0.78	56.67	70.8	5.0	151.5	0.46	12.5	9.3	0.58	31.3	6.0	3.8	15.8	4.1
73	IL-73	0.70	61.36	72.2	3.0	146.1	0.54	2.9	3.2	0.60	46.7	5.5	3.9	15.8	3.8
74	IL-74	0.62	63.61	76.6	0.0	157.7	0.53	39.9	13.3	0.55	24.5	5.7	4.0	12.9	3.8
75	IL-75	1.35	17.47	68.1	1.1	144.2	0.42	13.4	0.2	0.83	27.0	6.1	3.5	14.5	3.5
76	IL-76	1.07	32.21	70.7	0.6	171.1	0.64	24.1	0.2	0.71	31.9	6.4	3.1	16.0	3.5
77	IL-77	1.15	26.08	70.8	2.4	149.3	0.62	33.6	3.1	0.70	29.0	5.6	3.5	15.4	3.8
78	IL-78	0.94	33.74	71.4	2.0	144.6	0.56	3.3	5.8	0.62	45.2	7.0	3.9	16.2	3.3
79	IL-79	0.40	95.75	74.4	2.1	148.3	0.50	4.3	2.6	0.34	31.8	7.0	4.5	17.1	4.6
80	IL-80	0.63	64.64	75.4	1.1	147.5	0.49	1.8	16.3	0.33	57.7	5.8	4.5	16.1	4.2
81	IL-81	0.61	67.90	75.7	-0.4	168.0	0.49	3.3	3.0	0.57	45.7	6.7	4.2	16.2	4.1
82	IL-82	0.51	81.70	71.9	2.9	127.0	0.50	9.5	2.5	0.47	56.6	6.0	3.8	15.9	4.3
83	IL-83	0.34	96.02	82.1	0.1	143.4	0.57	8.8	4.1	0.29	58.1	4.7	5.0	13.5	3.9
84	IL-84	0.98	51.23	80.2	1.5	151.4	0.64	2.4	26.7	0.38	56.6	4.0	4.6	11.5	4.6
85	IL-85	0.82	50.57	81.2	0.5	127.8	0.62	1.8	0.2	0.59	53.2	4.4	4.4	15.8	4.4
86	IL-86	0.75	55.32	78.9	1.9	177.7	0.54	11.7	0.0	0.58	56.9	4.0	4.1	15.0	4.2

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Ear	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Rot	Sen.	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
87	IL-87	0.13	109.89	82.1	1.1	127.1	0.50	9.2	3.2	0.25	102.3	5.6	5.1	14.0	4.7
88	IL-88	0.41	80.71	77.2	2.5	166.4	0.47	-6.5	4.3	0.66	59.0	6.1	4.2	14.4	4.2
89	IL-89	0.67	58.37	76.4	1.0	129.7	0.49	5.8	3.3	0.54	41.9	5.5	4.0	15.5	3.9
90	IL-90	0.77	50.11	74.7	0.9	130.7	0.53	-2.2	6.8	0.67	54.0	6.8	4.3	15.3	3.8
91	IL-91	0.51	65.82	80.3	-0.6	133.8	0.54	3.1	-0.1	0.68	71.8	5.5	4.5	14.8	4.5
92	IL-92	0.97	50.04	80.8	0.6	139.5	0.55	1.0	0.1	0.65	41.6	5.3	3.2	10.5	4.0
93	IL-93	0.53	77.16	78.8	1.8	128.3	0.56	12.2	9.1	0.48	43.1	5.0	4.0	16.2	4.5
94	IL-94	0.21	103.85	84.6	-2.1	133.6	0.52	3.6	0.4	0.33	66.2	5.1	4.6	15.6	4.5
95	IL-95	0.92	39.36	72.5	0.5	114.1	0.54	2.5	0.8	0.63	34.7	7.3	3.9	14.1	4.2
96	IL-96	1.11	42.14	70.6	2.0	106.1	0.51	3.9	-0.2	0.86	30.7	5.4	4.1	12.5	3.8
97	IL-97	1.09	41.17	74.8	1.5	168.6	0.58	21.9	0.2	0.49	44.2	5.3	3.9	15.0	4.2
98	IL-98	0.91	38.20	70.0	1.1	139.7	0.58	21.8	-0.2	0.76	18.2	5.5	3.5	14.0	3.8
99	IL-99	1.43	25.98	72.3	-0.4	148.6	0.44	15.7	0.6	0.71	20.0	6.3	3.0	16.8	3.6
100	IL-100	0.39	86.80	81.6	2.6	161.6	0.63	5.4	5.9	0.39	59.3	5.4	3.8	16.2	3.7
101	IL-101	1.17	25.67	74.3	-0.1	166.0	0.52	-0.5	2.7	0.88	21.9	6.1	3.1	16.4	3.2
102	IL-102	0.39	91.52	76.4	0.6	151.6	0.62	9.0	6.6	0.37	37.7	7.7	3.8	16.6	3.8
103	IL-103	0.56	73.26	76.2	-0.3	159.3	0.71	19.4	-0.1	0.59	37.1	5.9	3.7	12.0	4.1
104	IL-104	0.79	49.46	75.2	-0.3	142.7	0.47	19.7	0.4	0.65	25.6	6.4	3.3	15.7	4.1
105	IL-105	1.15	23.36	76.1	-0.4	160.9	0.46	2.2	2.4	0.74	31.9	6.2	3.7	15.4	3.8
106	IL-106	1.21	36.04	69.1	5.0	149.7	0.57	11.1	3.1	0.60	23.5	6.2	2.9	16.3	3.6
107	IL-107	1.33	22.30	72.5	-1.4	151.0	0.48	2.0	10.5	0.52	23.2	5.9	2.9	13.5	3.2
108	IL-108	2.05	5.17	69.6	-0.5	167.7	0.60	5.9	0.2	0.87	18.3	6.5	2.7	14.9	2.8
Mean		**0.82**	**54.21**	**73.1**	**1.5**	**147.3**	**0.53**	**9.1**	**3.8**	**0.61**	**38.7**	**6.2**	**3.8**	**15.3**	**3.9**
LSD		**0.641**	**46.11**	**2.0**	**1.7**	**34.6**	**0.12**	**1.4**	**12.9**	**0.27**	**-**	**1.0**	**0.3**	**1.03**	**0.8**
MSe		**0.12**	**661.13**	**1.1**	**0.8**	**303.9**	**0.00**	**125.4**	**42.6**	**0.02**	**364.4**	**0.4**	**0.3**	**2.0**	**0.2**
p		**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**	**0.001**	**0.026**	**0.045**		**0.000**	**0.000**	**0.000**	**0.000**
Min		**0.13**	**-9.70**	**66.4**	**-2.1**	**106.1**	**0.38**	**-6.5**	**-1.1**	**0.19**	**9.6**	**4.0**	**2.7**	**10.5**	**2.8**
Max		**2.08**	**109.89**	**84.6**	**5.7**	**186.0**	**0.71**	**45.7**	**30.2**	**0.93**	**102.3**	**7.9**	**5.1**	**17.2**	**4.9**

(2-2.b) Chiredzi managed drought under heat stress

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
1	IL-1	0.32	76.40	60.5	7.9	177.4	0.47	12.5	11.4	0.23	23.3	5.1	2.1	15.5	5.0
2	IL-2	0.63	49.98	63.7	6.3	169.8	0.54	6.3	29.9	0.38	13.4	6.2	3.2	15.3	4.5
3	IL-3	0.21	80.04	58.2	8.2	196.4	0.51	3.3	-0.8	0.25	37.7	5.4	2.7	15.7	4.0
4	IL-4	0.88	40.97	55.9	9.5	167.2	0.44	5.9	0.5	0.34	35.3	5.0	2.8	16.8	4.0
5	IL-5	0.07	93.00	61.9	5.9	165.9	0.45	-0.9	-0.9	0.12	87.1	5.7	3.5	16.2	5.1
6	IL-6	0.24	74.69	63.4	8.2	170.6	0.43	1.8	-1.5	0.41	19.6	6.9	2.6	15.7	4.5
7	IL-7	1.05	43.00	60.1	5.9	180.7	0.45	10.6	0.9	0.48	35.4	6.4	2.2	15.7	5.0
8	IL-8	0.41	64.11	65.0	5.2	160.4	0.47	7.2	6.5	0.44	41.9	6.3	4.2	13.7	5.0
9	IL-9	0.85	44.10	59.8	5.8	186.8	0.57	5.5	0.6	0.29	17.0	5.4	4.0	17.0	5.0
10	IL-10	0.77	43.32	56.4	12.5	163.9	0.61	7.4	1.3	0.48	15.8	6.2	3.0	16.2	4.5
11	IL-11	0.46	71.79	60.1	2.1	174.3	0.47	2.1	6.9	0.25	54.3	5.6	2.7	16.6	4.0
12	IL-12	-0.03	95.99	64.9	8.7	166.6	0.51	3.0	-1.2	0.19	40.9	7.9	2.7	17.0	5.0
13	IL-13	0.89	48.61	62.7	4.5	170.9	0.39	2.5	5.4	0.58	44.7	6.1	2.1	16.1	4.6
14	IL-14	0.04	90.86	65.6		178.2	0.50	-0.7	4.0	0.09		6.9	3.7	14.6	5.0
15	IL-15	0.32	77.02	54.7	3.9	208.8	0.37	2.6	-0.3	0.27	42.1	6.6	3.1	16.9	4.5
16	IL-16	1.03	47.72	65.8	2.2	160.3	0.44	-0.5	0.4	0.48	17.8	5.8	4.2	15.8	5.0
17	IL-17	0.90	33.41	56.3		159.5	0.55	3.1	4.9	0.38	28.4	5.6	3.7	16.1	4.5
18	IL-18	0.24	81.92	53.2	1.0	183.3	0.51	3.4	13.7	0.16	50.2	8.4	3.9	13.9	4.4
19	IL-19					141.2	0.52	3.1	-1.4			6.1		14.4	
20	IL-20	0.72	51.72	63.0	7.2	168.4	0.50	5.9	-4.5	0.45	24.4	6.3	2.9	15.4	4.5
21	IL-21	0.57	53.84	63.3	5.3	199.6	0.39	11.1	10.3	0.38	51.8	7.2	3.1	13.4	4.9
22	IL-22	1.08	39.32	57.5	11.0	179.1	0.39	6.3	4.5	0.46	24.7	6.8	3.6	14.3	4.0
23	IL-23	0.97	35.08	59.5	10.1	172.3	0.51	-0.7	4.5	0.41	30.3	7.1	2.6	16.3	4.0
24	IL-24	0.17	88.09	58.7	17.5	157.5	0.47	0.3	2.0	0.25	24.4	4.8	2.7	16.0	5.0
25	IL-25	0.26	77.19	57.7	7.5	168.2	0.52	2.5	7.7	0.52	8.3	7.5	3.2	14.9	5.0
26	IL-26	-0.06	107.15	66.1	8.1	182.5	0.38	-0.3	4.1	0.24	17.7	6.5	2.8	15.2	5.0
27	IL-27	0.15	78.97	58.6	10.8	181.4	0.47	8.7	8.2	0.46	51.2	6.2	2.9	15.0	5.0
28	IL-28	0.12	84.73	61.6	4.2	164.7	0.40	6.1	8.7	0.26	81.1	4.8	3.4	16.1	5.0

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
29	IL-29	0.48	65.32	55.3	5.4	199.8	0.43	5.0	0.7	0.21	41.3	6.1	3.2	16.8	5.1
30	IL-30	1.22	29.27	64.9	6.2	173.3	0.57	3.3	2.1	0.59	30.3	5.5	3.4	15.0	4.0
31	IL-31	1.56	23.84	58.7	10.9	152.9	0.47	7.9	1.7	0.52	26.8	6.9	3.8	17.0	4.0
32	IL-32	0.13	89.65	61.9		183.9	0.43	2.3	8.8	0.14	30.5	6.1	2.6	16.5	4.4
33	IL-33	0.61	56.81	53.7	14.4	188.2	0.44	10.5	5.5	0.49	37.8	5.5	2.9	17.2	5.0
34	IL-34	0.29	78.06	61.1	-0.6	175.2	0.42	1.6	-1.3	0.22	21.9	6.7	3.2	16.1	4.5
35	IL-35	0.47	69.98	59.8	0.8	165.1	0.48	-0.6	7.0	0.28	38.8	5.9	2.5	16.5	5.0
36	IL-36	0.99	36.72	58.0	6.4	178.8	0.41	-1.2	0.9	0.64	29.7	5.6	2.4	17.1	4.1
37	IL-37	0.20	67.92	54.7	-0.2	160.4	0.41	1.5	-1.3	0.19	30.7	6.0	2.6	15.4	5.1
38	IL-38	0.83	50.63	65.7	3.0	180.0	0.46	7.1	1.2	0.40	17.2	6.1	4.3	15.0	5.0
39	IL-39	0.82	42.09	68.2	2.8	194.8	0.57	3.3	8.2	0.79	38.4	7.0	2.4	14.1	5.0
40	IL-40	0.89	39.97	57.8	2.8	177.0	0.45	5.8	5.3	0.67	41.6	4.3	2.7	15.6	5.0
41	IL-41	0.38	72.18	57.8	11.2	198.1	0.47	2.1	-1.4	0.60	32.3	4.6	3.2	14.5	5.0
42	IL-42	0.08	89.16	62.8	3.3	177.9	0.43	-0.9	-0.9	0.23	20.0	7.7	2.7	15.3	5.1
43	IL-43	0.82	40.41	69.5	0.8	181.5	0.35	-1.4	1.9	0.42	40.3	6.7	3.5	17.2	4.5
44	IL-44	0.36	72.41	71.9	-0.3	171.2	0.54	3.3	1.9	0.24	48.0	6.4	3.3	15.0	4.9
45	IL-45	0.43	63.39	57.5	9.9	188.6	0.44	9.4	-1.1	0.47	29.6	6.4	3.5	14.6	4.5
46	IL-46	0.81	40.36	58.2	0.7	167.7	0.57	-0.2	6.6	0.45	22.7	7.5	3.4	16.3	4.5
47	IL-47	0.55	53.36	59.1	2.1	167.5	0.50	-0.4	-3.1	0.41	22.6	5.9	3.3	16.7	4.5
48	IL-48	0.55	61.35	65.9	4.0	174.6	0.51	5.1	1.4	0.39	30.7	5.3	3.3	17.2	4.5
49	IL-49	0.98	35.73	52.6	13.7	182.3	0.47	-0.3	2.2	0.38	11.5	5.2	2.9	16.1	4.5
50	IL-50	0.56	57.48	65.7	1.4	170.4	0.52	-0.5	-0.5	0.51	30.4	6.3	3.3	15.5	5.0
51	IL-51	0.62	49.87	55.8	4.4	183.3	0.39	11.7	6.0	0.35	42.1	6.1	3.8	17.2	5.0
52	IL-52	0.03	94.42	65.3	5.6	179.6	0.48	-0.4	0.6	0.27	73.4	6.1	3.1	14.7	5.1
53	IL-53	1.36	26.32	64.2	3.2	169.2	0.55	14.7	11.4	0.54	19.5	5.1	3.1	16.4	4.5
54	IL-54	0.58	54.75	55.7	1.9	166.2	0.42	7.4	4.1	0.40	57.8	6.6	2.4	13.4	5.0
55	IL-55	0.36	63.62	54.8	3.8	163.9	0.58	8.2	-0.2	0.40	18.4	6.1	3.7	17.1	4.6
56	IL-56	0.54	57.74	61.0	11.4	179.2	0.52	12.1	0.9	0.40	18.0	6.9	3.7	16.0	5.0
57	IL-57	0.38	70.53	66.0	2.1	159.2	0.64	6.0	2.8	0.33	37.8	3.3	2.3	16.3	5.0
58	IL-58	0.18	71.58	59.1	13.8	171.4	0.50	-1.5	2.2	0.71	39.0	6.9	3.4	15.2	5.1

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
59	IL-59	0.20	86.89	65.1	3.9	183.6	0.48	9.1	8.7	0.29	55.3	4.7	2.6	15.3	5.0
60	IL-60	0.76	49.55	65.5	4.8	193.6	0.49	-0.9	-3.6	0.60	24.8	4.0	2.4	16.6	4.5
61	IL-61	0.23	80.76	64.4		174.9	0.38	-0.5	-2.3	0.18	35.5	5.9	2.8	16.2	4.5
62	IL-62	1.01	32.13	58.6	10.7	180.8	0.42	4.4	5.7	0.47	48.6	6.9	3.2	16.5	4.5
63	IL-63	0.11	89.06	59.9	12.3	176.9	0.41	2.9	8.0	0.20	85.4	6.2	2.4	17.1	4.8
64	IL-64	0.45	58.11	52.2	-0.3	202.1	0.45	2.9	-1.6	0.35	25.0	7.8	3.4	16.2	4.6
65	IL-65	0.01	90.35	57.8	10.9	149.9	0.54	-1.1	-4.2	0.17	72.0	6.5	2.8	15.6	5.1
66	IL-66	0.02	92.42	57.1	16.6	161.4	0.42	4.5	5.5	0.17	36.7	7.8	2.5	15.9	5.0
67	IL-67	0.77	48.84	62.6	3.6	174.8	0.53	3.2	-1.8	0.44	22.4	6.9	2.1	15.5	4.5
68	IL-68	0.73	50.78	59.4	1.6	168.4	0.63	-0.5	-0.6	0.62	23.5	6.9	3.4	12.8	5.0
69	IL-69	0.49	63.70	65.0	-0.1	181.4	0.48	1.7	6.1	0.46	43.5	7.7	2.8	15.5	4.5
70	IL-70	0.29	77.98	61.6	5.8	182.1	0.47	1.8	4.6	0.20	60.4	8.5	3.6	15.9	5.0
71	IL-71	0.24	76.57	59.9	12.5	161.0	0.55	-0.6	10.1	0.21	31.5	7.3	3.9	16.4	4.5
72	IL-72	0.12	92.79	59.5	15.3	177.6	0.44	2.1	2.3	0.24	54.7	5.3	3.3	17.0	5.0
73	IL-73	1.23	31.43	58.5	4.2	179.8	0.54	2.4	0.4	0.61	18.4	5.7	3.1	14.8	4.5
74	IL-74	0.11	83.53	61.4	3.3	177.3	0.42	-0.9	1.0	0.29	29.9	6.2	4.1	13.5	5.0
75	IL-75	0.61	67.00	70.1	1.2	183.3	0.46	5.3	2.5	0.15	49.8	6.9	3.0	15.4	5.0
76	IL-76	1.28	26.72	63.4	8.5	150.4	0.55	2.9	23.0	0.60	34.4	6.8	3.6	15.4	5.0
77	IL-77	0.76	42.98	59.0	6.4	192.3	0.45	-0.9	-0.1	0.43	49.6	6.6	3.1	16.1	4.5
78	IL-78	-0.07	98.32	60.8	7.6	167.9	0.53	-0.6	4.4	0.20	39.5	6.3	3.1	15.9	5.1
79	IL-79	0.74	40.03	65.8	1.2	185.3	0.43	-0.5	4.5	0.52	22.9	6.1	4.5	15.2	5.1
80	IL-80	0.43	64.61	65.6	4.9	175.4	0.56	2.5	13.5	0.40	34.1	6.5	3.3	15.1	4.5
81	IL-81	1.12	41.22	65.5	5.4	168.5	0.48	9.7	4.6	0.45	33.2	5.5	3.7	15.9	5.0
82	IL-82	0.88	43.89	59.5	6.2	169.6	0.53	-1.4	9.2	0.76	24.2	6.4	2.8	15.2	4.5
83	IL-83	0.48	67.67	68.9	0.8	180.9	0.42	2.2	5.6	0.50	41.6	4.2	4.2	13.9	5.0
84	IL-84	0.53	69.60	67.8	0.8	168.7	0.54	3.3	12.8	0.42	26.2	2.9	3.5	13.0	5.0
85	IL-85	0.97	40.89	73.0	1.3	220.4	0.40	-0.6	-0.4	0.77	28.9	4.3	4.0	15.4	5.0
86	IL-86	0.78	45.34	72.7		199.2	0.40	2.3	1.9	0.38	25.7	5.3	4.2	16.6	5.0
87	IL-87	0.03	95.65	71.0	0.9	175.8	0.52	5.6	5.1	0.17	23.4	2.6	3.6	16.4	5.0
88	IL-88	0.04	84.21	67.8	1.9	174.8	0.51	3.0	3.8	0.30	48.8	4.6	3.8	14.9	5.1

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
89	IL-89	0.34	75.70	66.3	2.5	175.4	0.51	5.2	4.7	0.36	47.8	5.5	4.2	15.7	5.0
90	IL-90	0.92	43.30	61.0	6.7	184.3	0.54	-1.3	-4.4	0.67	36.7	5.5	3.9	14.7	5.0
91	IL-91	0.39	63.58	69.0	0.7	168.7	0.53	-1.0	4.3	0.47	24.0	4.2	4.1	15.3	5.0
92	IL-92	1.83	5.65	67.2	2.2	179.8	0.55	-1.1	-1.1	0.72	24.4	5.9	3.5	14.8	4.5
93	IL-93	0.46	58.92	68.6	1.1	162.8	0.45	5.6	15.0	0.41	35.3	3.9	3.1	15.9	4.5
94	IL-94	0.34	66.68	75.2	0.3	154.6	0.44	-1.6	-3.8	0.44	56.6	4.5	4.5	14.2	5.0
95	IL-95	0.26	79.69	64.8	-1.5	167.9	0.46	8.2	0.7	0.31	27.3	8.1	2.8	16.1	5.0
96	IL-96	0.86	37.29	65.4	2.0	189.0	0.45	-0.2	1.5	0.68	22.4	5.8	2.2	15.2	4.5
97	IL-97	0.20	79.43	65.6	-0.3	207.6	0.38	-0.4	-2.7	0.30	27.4	6.1	3.2	15.3	5.0
98	IL-98	1.03	35.77	62.0	3.6	184.3	0.44	8.5	4.0	0.73	34.0	6.4	2.4	16.1	4.5
99	IL-99	1.34	23.90	61.5	4.3	163.2	0.50	2.0	2.6	0.58	17.7	5.9	3.1	15.9	4.5
100	IL-100	1.30	24.26	68.9	1.5	171.4	0.48	3.1	7.7	0.68	17.7	5.8	2.3	15.9	5.0
101	IL-101	1.18	25.01	66.3	1.5	177.2	0.41	-1.3	-2.6	0.75	13.6	6.2	3.9	14.8	4.5
102	IL-102	0.73	51.31	71.4	1.0	192.2	0.43	5.8	-0.3	0.42	45.7	4.2	2.6	15.8	4.9
103	IL-103	0.83	41.07	66.6	3.8	201.5	0.37	1.6	9.4	0.53	19.8	6.1	3.3	16.1	4.5
104	IL-104	0.39	72.46	66.6	4.4	197.5	0.42	3.4	1.4	0.28	47.0	6.2	3.2	17.0	5.0
105	IL-105	0.83	46.28	66.3	5.3	188.0	0.48	2.5	-2.3	0.29	55.8	5.6	2.8	14.9	4.1
106	IL-106	0.03	93.09	61.1	8.4	204.7	0.31	8.4	2.9	0.27	30.0	7.0	3.3	15.4	5.0
107	IL-107	1.89	12.64	60.4	3.2	185.4	0.48	2.7	-1.2	0.45	22.1	7.0	3.5	16.6	3.4
108	IL-108	1.29	37.83	60.6	7.3	170.9	0.46	-1.5	1.2	0.62	45.3	6.1	3.8	15.1	4.5
Mean		**0.59**	**59.86**	**62.3**	**5.2**	**176.9**	**0.47**	**3.2**	**3.4**	**0.41**	**34.9**	**6.0**	**3.2**	**15.6**	**4.7**
LSD		**0.87**	**42.27**	**6.1**	**2.0**	**31.5**	**0.16**	**10.6**	**12.3**	**0.30**	**32.7**	**2.3**	**1.0**	**2.4**	**0.9**
MSe		**0.21**	**545.87**	**8.5**	**11.2**	**448.6**	**0.01**	**28.4**	**43.5**	**0.02**	**282.2**	**2.3**	**0.3**	**1.6**	**0.2**
CV		**77.49**	**39.03**	**4.7**	**63.9**	**12.0**	**18.16**	**164.0**	**195.2**	**37.93**	**48.1**	**25.3**	**16.6**	**8.0**	**9.4**
p		**0.000**	**0.000**	**0.000**	**0.010**	**0.000**	**0.041**	**0.420**	**0.007**	**0.000**	**0.000**	**0.000**	**0.000**	**0.052**	**0.019**
Min		**-0.07**	**5.65**	**52.2**	**-1.5**	**141.2**	**0.31**	**-1.6**	**-4.5**	**0.09**	**8.3**	**2.6**	**2.1**	**12.8**	**3.4**
Max		**1.89**	**107.15**	**75.2**	**17.5**	**220.4**	**0.64**	**14.7**	**29.9**	**0.79**	**87.1**	**8.5**	**4.5**	**17.2**	**5.1**

(2-2.c) Save Valley fully-irrigated under heat stress

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
1	IL-1	1.59	55.13	60.4	0.2	127.5	0.53	-	-	0.67	20.8	-	0.9	16.4	3.8
2	IL-2	2.31	26.26	57.5	1.1	140.3	0.49	-	-	0.57	39.1	-	1.1	15.5	3.2
3	IL-3	1.25	67.25	55.8	0.1	125.3	0.64	-	-	0.46	39.8	-	1.0	14.4	2.9
4	IL-4	1.20	62.40	55.7	1.1	108.9	0.61	-	-	0.51	38.3	-	1.1	16.4	4.1
5	IL-5	1.43	54.72	57.4	0.2	119.8	0.51	-	-	0.77	25.6	-	0.9	14.5	2.9
6	IL-6	1.15	64.81	58.5	0.5	124.7	0.47	-	-	0.43	38.0	-	1.1	15.0	3.0
7	IL-7	1.62	43.58	56.0	0.2	104.8	0.57	-	-	0.60	31.9	-	1.0	14.8	3.5
8	IL-8	1.33	58.48	56.6	2.1	114.1	0.50	-	-	0.56	38.0	-	2.2	15.9	4.1
9	IL-9	1.45	54.65	57.8	1.3	123.9	0.60	-	-	0.45	54.2	-	1.5	14.8	3.7
10	IL-10	1.45	55.46	53.2	2.9	117.8	0.45	-	-	0.51	23.0	-	0.9	15.4	2.5
11	IL-11	1.77	38.76	57.6	1.2	143.8	0.50	-	-	0.71	19.5	-	0.9	15.3	3.1
12	IL-12	0.74	88.43	62.0	9.2	116.7	0.58	-	-	0.50	27.3	-	1.0	15.0	4.1
13	IL-13	1.98	28.36	58.8	5.4	116.6	0.53	-	-	0.67	22.9	-	1.1	16.3	3.8
14	IL-14	1.13	77.45	59.3	2.1	135.6	0.54	-	-	0.34	40.2	-	1.2	15.0	2.8
15	IL-15	1.89	32.11	56.8	6.2	132.3	0.47	-	-	0.74	27.6	-	1.1	14.9	3.7
16	IL-16	1.60	47.31	57.2	2.4	141.2	0.53	-	-	0.69	25.9	-	1.0	14.9	3.6
17	IL-17	2.07	22.27	63.6	0.0	119.6	0.60	-	-	0.62	32.8	-	1.4	9.9	2.6
18	IL-18	1.12	69.97	55.2	0.0	110.3	0.54	-	-	0.50	31.2	-	1.4	17.0	4.2
19	IL-19	1.01	87.02	58.7	0.1	125.0	0.53	-	-	0.64	45.4	-	1.8	11.8	4.2
20	IL-20	2.26	32.62	55.4	1.1	135.2	0.44	-	-	0.61	22.7	-	0.9	14.3	2.5
21	IL-21	1.25	59.30	58.7	1.5	122.2	0.49	-	-	0.57	32.1	-	1.2	16.5	3.8
22	IL-22	1.54	49.96	57.8	0.5	118.7	0.54	-	-	0.54	21.3	-	1.5	15.4	3.2
23	IL-23	1.74	36.07	57.1	2.3	124.5	0.52	-	-	0.68	28.3	-	1.0	16.9	3.6
24	IL-24	0.86	89.41	61.2	0.0	136.5	0.57	-	-	0.39	33.7	-	0.9	14.9	3.4
25	IL-25	1.85	32.73	57.1	0.1	126.1	0.59	-	-	0.81	24.4	-	1.2	14.9	3.6
26	IL-26	1.25	62.16	62.4	2.9	127.7	0.51	-	-	0.46	47.1	-	0.9	11.4	4.0
27	IL-27	0.98	69.17	57.0	3.5	133.4	0.54	-	-	0.48	38.1	-	1.1	16.5	3.4
28	IL-28	0.81	94.63	61.4	1.0	104.6	0.56	-	-	0.46	41.3	-	1.1	13.9	3.8

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Ear	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Rot	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
29	IL-29	1.46	59.31	56.7	0.0	104.4	0.56	-	-	0.52	24.7	-	1.4	16.5	3.4
30	IL-30	0.98	76.84	64.7	0.1	130.2	0.57	-	-	0.67	28.2	-	1.2	13.9	3.8
31	IL-31	2.28	9.83	65.0	2.2	150.1	0.58	-	-	0.61	21.5	-	2.5	15.3	2.3
32	IL-32	1.15	75.92	57.6	0.4	120.7	0.45	-	-	0.66	38.9	-	1.6	14.9	4.1
33	IL-33	2.05	47.25	58.9	0.0	126.5	0.56	-	-	0.57	36.0	-	1.4	15.4	2.9
34	IL-34	1.83	30.16	57.4	1.3	118.6	0.48	-	-	0.72	32.2	-	1.6	15.4	2.9
35	IL-35	1.58	54.71	58.3	1.0	129.7	0.52	-	-	0.68	30.6	-	1.0	16.0	3.5
36	IL-36	1.44	51.83	58.3	0.6	113.6	0.60	-	-	0.69	33.8	-	1.1	14.9	3.9
37	IL-37	0.65	88.26	58.8	0.5	116.5	0.52	-	-	0.52	64.9	-	1.0	16.5	5.1
38	IL-38	1.39	58.09	57.8	2.6	109.5	0.61	-	-	0.68	47.2	-	1.0	15.4	3.5
39	IL-39	1.43	62.37	63.6	6.2	140.6	0.51	-	-	0.50	68.6	-	0.9	15.4	3.9
40	IL-40	1.64	40.76	56.0	3.1	111.9	0.57	-	-	0.90	35.0	-	1.2	13.9	2.6
41	IL-41	1.46	54.08	56.0	1.7	131.6	0.51	-	-	0.39	52.0	-	1.1	14.9	3.5
42	IL-42	1.85	26.83	57.8	0.5	150.5	0.55	-	-	0.85	29.7	-	1.0	14.4	3.4
43	IL-43	1.79	40.84	58.5	2.2	147.7	0.54	-	-	0.58	25.8	-	1.4	16.3	2.4
44	IL-44	1.12	72.95	58.1	3.1	143.9	0.52	-	-	0.45	24.4	-	1.0	17.0	3.4
45	IL-45	0.81	95.99	63.1	7.3	145.5	0.49	-	-	0.44	23.3	-	1.3	13.9	3.3
46	IL-46	1.16	62.21	55.7	-0.1	101.3	0.55	-	-	0.50	38.4	-	1.2	17.0	4.1
47	IL-47	2.03	27.15	56.9	0.8	134.9	0.65	-	-	0.71	38.7	-	2.0	14.8	3.8
48	IL-48	2.42	20.21	63.5	0.1	144.2	0.55	-	-	0.93	13.6	-	1.2	14.5	2.4
49	IL-49	1.15	72.31	50.8	5.0	118.2	0.48	-	-	0.51	23.3	-	0.9	16.0	4.0
50	IL-50	0.80	96.66	60.0	0.7	129.5	0.50	-	-	0.39	38.7	-	0.8	14.4	3.9
51	IL-51	1.64	43.08	57.3	-1.5	143.9	0.45	-	-	0.80	28.7	-	1.0	14.5	3.6
52	IL-52	1.22	62.79	61.1	5.6	123.4	0.51	-	-	0.53	38.8	-	1.1	13.5	3.8
53	IL-53	2.13	29.24	60.3	0.7	135.2	0.61	-	-	0.82	28.7	-	1.0	11.9	2.6
54	IL-54	1.82	45.09	51.9	3.1	131.1	0.63	-	-	0.63	43.8	-	1.2	10.8	2.7
55	IL-55	1.17	74.80	56.9	4.7	124.5	0.56	-	-	0.57	57.4	-	1.2	15.4	4.3
56	IL-56	1.60	47.17	62.7	0.2	154.5	0.48	-	-	0.72	27.7	-	1.5	14.9	3.4
57	IL-57	1.77	40.44	61.0	1.4	121.2	0.49	-	-	0.72	16.6	-	1.1	15.4	3.1
58	IL-58	0.91	85.90	57.4	0.1	120.1	0.51	-	-	0.38	32.5	-	1.0	13.4	3.0

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Ear	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Rot	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
59	IL-59	1.50	45.63	58.6	1.6	104.0	0.53	-	-	0.66	37.9	-	0.9	14.9	4.1
60	IL-60	2.05	32.89	61.8	1.1	144.6	0.55	-	-	0.82	25.8	-	0.8	14.9	3.7
61	IL-61	0.73	88.82	56.8	2.8	151.5	0.51	-	-	0.29	18.5	-	1.0	15.8	3.0
62	IL-62	2.42	13.57	55.9	0.9	123.0	0.56	-	-	0.63	24.5	-	0.9	16.4	3.1
63	IL-63	1.79	35.15	57.8	1.5	113.6	0.58	-	-	0.64	30.2	-	1.1	16.4	3.4
64	IL-64	1.12	75.52	59.6	1.7	145.7	0.44	-	-	0.54	35.0	-	0.9	15.9	4.5
65	IL-65	0.66	87.91	57.5	0.7	139.4	0.53	-	-	0.32	40.4	-	0.9	15.5	3.5
66	IL-66	0.81	81.85	57.9	1.6	156.2	0.45	-	-	0.41	29.8	-	1.1	14.9	3.4
67	IL-67	0.96	77.84	59.0	0.1	133.1	0.53	-	-	0.43	41.7	-	1.1	16.4	4.0
68	IL-68	1.73	33.57	56.4	0.7	112.1	0.60	-	-	0.83	25.6	-	1.0	13.9	3.8
69	IL-69	1.88	31.25	62.1	4.2	147.9	0.52	-	-	0.74	28.8	-	1.2	16.3	3.2
70	IL-70	0.88	96.27	56.6	1.3	93.4	0.49	-	-	0.63	20.3	-	1.3	16.0	3.6
71	IL-71	1.11	69.28	58.0	0.3	137.8	0.56	-	-	0.55	49.4	-	1.3	14.4	2.8
72	IL-72	1.32	70.44	54.5	2.8	105.0	0.52	-	-	0.59	44.1	-	1.0	16.4	3.3
73	IL-73	1.44	68.60	56.9	1.2	104.3	0.54	-	-	0.67	25.8	-	1.5	15.5	3.4
74	IL-74	1.41	59.08	58.5	0.8	117.3	0.57	-	-	0.69	30.5	-	1.2	13.9	3.5
75	IL-75	1.74	41.18	51.6	0.8	121.6	0.50	-	-	0.63	26.4	-	1.0	16.4	3.3
76	IL-76	2.70	15.44	58.3	0.2	105.8	0.59	-	-	0.93	22.9	-	1.1	15.9	2.7
77	IL-77	2.01	24.71	57.7	0.7	136.0	0.50	-	-	0.71	31.5	-	1.0	15.9	3.4
78	IL-78	1.08	72.60	57.7	2.5	113.6	0.50	-	-	0.56	44.5	-	1.0	16.5	4.0
79	IL-79	1.26	74.01	63.6	0.7	141.4	0.49	-	-	0.71	21.9	-	1.7	13.4	3.2
80	IL-80	1.71	44.07	60.9	4.1	151.4	0.51	-	-	0.79	27.7	-	1.2	14.0	3.7
81	IL-81	2.13	22.31	62.2	0.0	147.6	0.49	-	-	0.76	28.1	-	1.5	15.4	3.2
82	IL-82	1.47	52.91	55.6	0.5	131.5	0.54	-	-	0.59	23.2	-	1.0	14.9	4.0
83	IL-83	0.79	86.10	68.6	1.1	143.6	0.55	-	-	0.83	18.4	-	2.3	8.4	3.8
84	IL-84	0.55	93.80	66.2	4.2	111.1	0.64	-	-	0.13	49.6	-	2.9	14.4	2.3
85	IL-85	1.79	33.00	67.0	0.0	134.8	0.60	-	-	0.71	22.5	-	2.2	12.9	2.2
86	IL-86	1.68	56.01	65.6	5.3	142.0	0.54	-	-	0.76	29.7	-	2.5	12.4	3.2
87	IL-87	0.84	91.01	65.7	0.8	134.0	0.51	-	-	0.56	22.5	-	2.2	15.4	4.2
88	IL-88	1.77	43.75	65.2	5.6	132.2	0.50	-	-	0.57	31.4	-	1.9	12.9	2.9

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
89	IL-89	1.35	51.64	62.4	0.4	119.9	0.47	-	-	0.55	21.0	-	1.9	16.5	3.6
90	IL-90	1.56	54.42	63.0	0.5	114.1	0.60	-	-	0.70	18.8	-	1.6	16.0	3.1
91	IL-91	1.14	69.79	66.2	0.3	103.5	0.62	-	-	0.75	16.8	-	1.5	15.9	4.1
92	IL-92	3.81	5.19	63.9	0.7	131.7	0.52	-	-	0.79	13.7	-	2.0	15.5	1.7
93	IL-93	1.46	52.99	65.9	0.2	100.9	0.60	-	-	0.77	25.2	-	1.0	9.9	4.2
94	IL-94	1.19	60.84	69.7	6.8	81.3	0.47	-	-	0.32	60.5	-	1.2	13.9	4.5
95	IL-95	0.64	98.75	62.5	0.1	127.0	0.53	-	-	0.39	25.8	-	1.3	16.4	4.6
96	IL-96	2.47	10.16	63.2	1.9	143.1	0.58	-	-	0.62	32.7	-	0.9	15.8	2.0
97	IL-97	1.07	79.00	64.2	2.2	119.9	0.55	-	-	0.67	37.8	-	1.2	11.9	2.7
98	IL-98	1.81	34.26	58.6	1.5	108.8	0.55	-	-	0.63	23.7	-	0.9	15.5	3.1
99	IL-99	2.15	24.86	55.3	0.2	122.4	0.48	-	-	0.72	22.2	-	1.0	14.9	3.7
100	IL-100	2.55	25.09	61.7	2.7	158.2	0.57	-	-	0.87	16.4	-	1.3	15.0	2.9
101	IL-101	2.92	18.13	60.3	0.0	129.7	0.50	-	-	0.98	15.8	-	0.7	15.9	2.4
102	IL-102	2.58	10.57	64.1	0.2	152.0	0.56	-	-	0.98	21.4	-	0.9	15.3	3.8
103	IL-103	1.04	68.62	60.7	1.9	135.2	0.60	-	-	0.37	37.6	-	1.7	11.4	2.1
104	IL-104	1.61	48.63	63.0	0.0	99.7	0.53	-	-	0.96	22.4	-	1.5	13.8	3.6
105	IL-105	0.82	84.73	60.1	0.1	96.4	0.53	-	-	0.46	42.1	-	1.1	16.5	4.3
106	IL-106	1.11	71.93	56.4	3.7	133.5	0.58	-	-	0.60	18.3	-	1.0	16.9	3.8
107	IL-107	3.11	1.01	60.0	0.5	118.7	0.55	-	-	0.73	29.5	-	1.4	16.5	3.0
108	IL-108	2.79	9.96	57.7	0.6	157.7	0.52	-	-	1.11	18.5	-	2.2	16.4	2.3
Mean		**1.54**	**53.82**	**59.5**	**1.6**	**126.7**	**0.54**	**-**	**-**	**0.62**	**31.3**	**-**	**1.3**	**14.9**	**3.4**
LSD		**1.26**	**52.97**	**2.9**	**1.7**	**35.5**	**0.13**	**-**	**-**	**0.33**	**27.2**	**-**	**0.6**	**3.4**	**1.3**
MSe		**0.44**	**818.72**	**2.3**	**0.8**	**329.5**	**0.00**	**-**	**-**	**0.04**	**195.0**	**-**	**0.1**	**2.9**	**0.4**
CV		**43.20**	**53.16**	**2.5**	**53.0**	**14.3**	**12.70**	**-**	**-**	**30.18**	**44.6**	**-**	**24.8**	**11.4**	**19.4**
p		**0.001**	**0.001**	**0.000**	**0.000**	**0.009**	**0.495**	**-**	**-**	**0.000**	**0.083**	**-**	**0.000**	**0.002**	**0.000**
Min		**0.55**	**1.01**	**50.8**	**-1.5**	**81.3**	**0.44**	**-**	**-**	**0.13**	**13.6**	**-**	**0.7**	**8.4**	**1.7**
Max		**3.81**	**98.75**	**69.7**	**9.2**	**158.2**	**0.65**	**-**	**-**	**1.11**	**68.6**	**-**	**2.9**	**17.0**	**5.1**

(2-2.d) Save Valley managed drought under heat stress

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Husk Cover	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem							
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	%	1-10	1-5	#	1-5
1	IL-1	1.40	28.11	80.4	1.2	128.2	0.40	-	-	0.84	7.9	36.7	-	1.3	9.5	3.8
2	IL-2	0.58	74.53	79.6	2.6	119.4	0.42	-	-	0.62	13.6	40.7	-	1.8	8.0	4.0
3	IL-3	0.71	70.79	82.7	-0.2	105.4	0.42	-	-	0.57	9.2	40.6	-	1.0	13.1	4.2
4	IL-4	1.24	35.12	78.0	2.7	95.8	0.30	-	-	0.60	22.5	42.7	-	0.9	14.3	3.5
5	IL-5	1.58	25.39	77.6	3.2	124.3	0.40	-	-	1.15	38.0	47.3	-	0.9	12.0	4.3
6	IL-6	0.85	62.16	79.5	3.2	124.5	0.36	-	-	0.52	9.4	38.3	-	0.9	11.9	3.7
7	IL-7	1.55	20.54	79.9	1.0	112.0	0.38	-	-	1.00	31.8	41.4	-	1.0	11.2	3.5
8	IL-8	0.63	73.35	80.1	0.3	115.9	0.40	-	-	0.57	19.7	34.6	-	2.9	9.8	4.3
9	IL-9	0.74	62.59	80.8	1.2	109.1	0.40	-	-	0.69	27.8	47.8	-	1.5	9.0	3.3
10	IL-10	0.52	77.31	79.0	4.6	95.5	0.38	-	-	0.54	1.5	25.2	-	0.9	9.0	4.5
11	IL-11	0.62	75.08	80.5	2.5	133.9	0.33	-	-	0.67	14.2	56.5	-	1.0	11.7	4.5
12	IL-12	0.97	57.22	82.7	1.4	108.7	0.34	-	-	0.72	23.1	36.8	-	1.3	10.9	3.5
13	IL-13	1.46	19.58	83.2	3.1	146.0	0.35	-	-	1.22	19.2	41.0	-	1.1	8.5	3.3
14	IL-14	0.37	93.80	78.3	0.0	94.5	0.32	-	-	0.36	12.8	59.7	-	0.9	12.5	4.8
15	IL-15	1.01	55.35	80.0	2.1	102.3	0.32	-	-	0.71	13.1	36.4	-	1.0	10.7	3.7
16	IL-16	2.75	0.51	83.3	1.0	170.0	0.38	-	-	0.89	10.1	13.4	-	1.2	11.8	1.5
17	IL-17	1.81	24.12	79.5	2.9	142.5	0.37	-	-	0.72	15.9	52.1	-	1.5	12.7	3.3
18	IL-18	0.61	74.04	76.4	3.5	98.1	0.49	-	-	0.74	16.5	43.3	-	2.0	9.6	4.8
19	IL-19	0.30	98.55	82.4	4.9	94.4	0.34	-	-	0.53	14.7	79.0	-	1.1	4.7	5.0
20	IL-20	0.83	60.87	80.6	1.5	98.8	0.47	-	-	0.85	32.0	37.6	-	1.5	8.3	3.7
21	IL-21	1.29	36.73	79.8	1.2	118.3	0.42	-	-	0.77	8.9	25.8	-	1.5	11.8	4.0
22	IL-22	0.75	65.46	79.7	1.4	111.3	0.36	-	-	0.54	-1.6	23.1	-	1.3	12.0	4.2
23	IL-23	1.34	32.26	80.3	1.0	115.3	0.35	-	-	0.76	13.9	75.7	-	2.0	12.1	4.3
24	IL-24	0.98	53.57	85.1	1.6	107.7	0.33	-	-	0.68	19.0	37.5	-	1.5	13.4	4.0
25	IL-25	1.12	47.74	83.3	.	129.3	0.36	-	-	0.63	11.7	26.7	-	1.0	13.0	4.0
26	IL-26	0.31	94.09	88.0	.	151.1	0.29	-	-	0.52	2.8	19.0	-	1.2	8.3	3.5
27	IL-27	0.09	103.47	78.6	5.1	96.9	0.33	-	-	0.28	21.8	67.7	-		12.7	5.0
28	IL-28	0.52	83.41	81.6	4.4	111.7	0.36	-	-	0.86	43.0	47.7	-	1.5	9.1	4.8

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Husk	Ear	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Cover	Rot	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	%	1-10	1-5	#	1-5
29	IL-29	1.06	44.06	76.9	1.0	112.9	0.37	-	-	0.49	17.8	54.0	-	0.9	12.1	3.8
30	IL-30	0.51	83.96	.	.	150.0	0.37	-	-	0.64	4.0	52.5	-	1.0	6.1	4.5
31	IL-31	1.19	39.17	80.0	2.1	99.8	0.36	-	-	0.61	19.9	39.1	-	2.0	11.3	4.0
32	IL-32	0.46	83.31	77.4	4.1	111.0	0.38	-	-	0.42	2.3	26.0	-	1.5	11.5	3.8
33	IL-33	1.91	16.61	76.5	4.0	109.3	0.39	-	-	0.85	20.1	29.8	-	1.5	13.7	3.3
34	IL-34	1.46	20.76	78.6	4.9	121.7	0.34	-	-	0.67	5.6	33.9	-	1.3	14.3	3.3
35	IL-35	0.86	64.25	82.4	3.1	117.6	0.33	-	-	1.07	18.3	27.2	-	1.0	5.4	3.8
36	IL-36	0.81	56.41	80.0	2.9	125.3	0.37	-	-	0.73	41.9	32.5	-	1.8	11.6	4.5
37	IL-37	0.35	88.96	76.1	2.9	98.1	0.37	-	-	0.36	18.5	46.5	-	1.1	12.3	5.0
38	IL-38	1.37	44.91	83.5	4.2	117.6	0.40	-	-	1.07	18.2	25.0	-	1.7	11.8	3.7
39	IL-39	0.31	95.76	84.8	1.9	103.5	0.33	-	-	0.22	-5.6	113.5	-	1.0	6.2	3.8
40	IL-40	1.20	33.47	76.3	3.9	116.1	0.38	-	-	0.74	60.7	38.3	-	1.0	12.6	4.5
41	IL-41	0.91	54.67	80.0	5.9	115.1	0.41	-	-	0.34	16.2	36.3	-	1.0	14.3	3.7
42	IL-42	1.26	31.81	79.4	0.3	135.8	0.39	-	-	0.99	13.2	38.5	-	1.0	11.0	4.0
43	IL-43	1.96	23.29	78.9	4.9	134.9	0.33	-	-	1.02	26.5	29.9	-	1.4	10.3	3.0
44	IL-44	1.66	23.76	78.7	3.2	104.9	0.43	-	-	0.56	-4.9	23.5	-	1.5	14.3	3.3
45	IL-45	0.64	76.79	81.6	1.9	139.3	0.37	-	-	0.81	10.1	47.7	-	1.3	6.9	4.5
46	IL-46	1.06	50.36	82.4	1.5	118.8	0.32	-	-	0.85	-0.5	28.0	-	1.0	12.0	3.8
47	IL-47	1.48	27.59	79.2	1.8	120.5	0.37	-	-	0.89	4.3	35.7	-	1.7	11.2	3.8
48	IL-48	0.92	57.70	83.0	0.1	123.6	0.39	-	-	0.56	12.0	58.9	-	1.5	11.4	4.5
49	IL-49	1.22	39.93	75.5	1.9	107.0	0.38	-	-	0.74	16.4	39.8	-	2.3	12.0	4.0
50	IL-50	0.79	61.49	.	.	154.0	0.36	-	-	0.76	-5.0	16.6	-	1.0	10.8	4.2
51	IL-51	1.07	47.82	78.1	0.8	121.3	0.42	-	-	0.58	35.9	47.0	-	1.9	13.3	3.8
52	IL-52	0.44	75.09	81.4	1.8	109.8	0.40	-	-	0.76	-0.7	41.7	-	1.0	6.5	5.0
53	IL-53	1.58	23.41	81.0	0.7	94.9	0.38	-	-	0.72	15.3	33.5	-	1.0	11.9	3.3
54	IL-54	0.25	97.30	82.7	0.9	108.0	0.32	-	-	0.24	5.5	73.4	-	1.3	6.5	4.5
55	IL-55	1.05	47.83	79.9	3.4	117.9	0.37	-	-	0.50	1.6	29.5	-	1.7	13.8	3.6
56	IL-56	0.66	72.52	82.3	2.2	123.7	0.38	-	-	0.71	10.8		-	1.4	8.0	3.2
57	IL-57	0.76	60.02	85.0	0.3	119.7	0.33	-	-	0.79	17.6	34.6	-	1.4	13.1	4.5
58	IL-58	0.70	73.72	78.3	2.2	130.3	0.36	-	-	0.49	1.9	50.0	-	1.0	13.4	4.5

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Husk Cover	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem							
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	%	1-10	1-5	#	1-5
59	IL-59	0.94	50.32	84.7	-0.1	111.5	0.40	-	-	0.55	7.4	42.4	-	0.9	12.6	4.3
60	IL-60	1.51	25.29	81.0	5.2	103.8	0.37	-	-	0.92	54.2	32.3	-	1.1	11.1	4.0
61	IL-61	0.74	71.54	78.7	1.1	101.8	0.39	-	-	0.79	5.8	21.1	-	1.0	10.2	4.2
62	IL-62	1.46	26.62	78.1	2.4	122.1	0.36	-	-	0.65	47.2	36.9	-	1.5	13.5	4.2
63	IL-63	1.54	22.00	80.9	2.7	112.1	0.34	-	-	0.95	65.8	49.2	-	1.0	14.2	4.0
64	IL-64	1.25	37.59	78.3	2.7	118.5	0.39	-	-	0.85	2.9	24.5	-	1.7	12.0	4.0
65	IL-65	0.46	90.90	78.3	8.4	110.7	0.35	-	-	0.31	23.5	53.7	-	1.0	12.8	5.0
66	IL-66	1.00	48.61	82.4	2.8	118.7	0.41	-	-	0.56	8.4	16.3	-	1.1	13.0	3.3
67	IL-67	0.89	59.26	82.1	2.6	117.5	0.34	-	-	0.95	25.9	33.9	-	1.1	7.3	4.0
68	IL-68	0.71	72.48	82.2	2.8	96.1	0.41	-	-	0.71	15.7	33.4	-	1.1	10.3	4.5
69	IL-69	1.62	20.57	84.6	1.4	125.1	0.44	-	-	0.74	24.0	21.5	-	1.0	12.4	3.2
70	IL-70	1.26	38.15	79.4	2.2	101.3	0.40	-	-	0.79	29.1	22.6	-	1.0	12.2	4.0
71	IL-71	1.99	12.35	77.6	0.7	137.0	0.39	-	-	0.94	18.5	29.4	-	1.8	12.9	3.2
72	IL-72	0.59	72.19	81.0	5.1	138.1	0.34	-	-	0.29	4.1	33.1	-	2.0	12.8	4.0
73	IL-73	1.20	38.20	80.1	1.0	118.9	0.40	-	-	0.93	17.9	29.0	-	1.6	10.4	3.3
74	IL-74	0.79	65.85	80.1	3.9	109.9	0.43	-	-	0.83	27.8	33.8	-	1.3	9.2	3.7
75	IL-75	1.36	27.60	76.1	1.9	130.7	0.37	-	-	0.66	8.6	29.8	-	1.5	12.8	3.5
76	IL-76	0.98	55.89	83.0	4.1	137.8	0.34	-	-	0.56	12.8	72.4	-	1.0	10.0	3.2
77	IL-77	0.96	56.44	78.5	5.4	100.0	0.38	-	-	0.68	25.2	27.5	-	0.9	11.4	4.0
78	IL-78	0.47	78.97	79.4	2.5	98.7	0.45	-	-	0.72	6.1	35.0	-	1.1	6.0	4.0
79	IL-79	0.41	95.52	80.8	3.0	114.1	0.44	-	-	0.44	7.6	47.8	-	2.0	12.3	4.5
80	IL-80	0.97	53.37	84.0	4.3	142.8	0.38	-	-	0.70	4.4	41.8	-	1.0	11.7	4.0
81	IL-81	0.38	84.10	85.0	0.2	136.4	0.33	-	-	0.49	32.5	50.9	-	3.1	11.2	4.8
82	IL-82	1.40	24.63	77.9	2.9	137.0	0.37	-	-	0.86	2.0	23.6	-	1.0	11.1	3.0
83	IL-83	0.65	69.69	.	.	99.7	0.37	-	-	0.86	8.9	40.5	-	1.5	7.3	3.8
84	IL-84	1.07	55.14	82.6	0.3	122.1	0.37	-	-	0.98	18.7		-	2.0	4.2	3.5
85	IL-85	0.24	99.66	.	.	122.2	0.39	-	-	0.66	69.3	85.1	-	3.0	4.5	5.0
86	IL-86	1.17	51.28	85.0	.	126.5	0.36	-	-	0.59	-4.7	68.8	-	2.2	8.4	4.0
87	IL-87	0.30	95.53	.	.	104.9	0.31	-	-	0.85	15.1	46.7	-	2.0	7.0	4.8
88	IL-88	0.42	87.93	85.2	.	141.4	0.34	-	-	0.47	7.4	60.8	-	2.2	7.2	4.0

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Husk Cover	Ear Rot	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem							
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	%	1-10	1-5	#	1-5
89	IL-89	0.33	92.52	86.5	.	152.6	0.28	-	-	0.58	20.4	26.4	-	1.4	7.9	4.5
90	IL-90	0.47	85.47	85.5	-0.3	91.8	0.42	-	-	0.63	-3.2	31.1	-	1.5	6.3	4.0
91	IL-91	0.59	77.22	87.0	-0.3	84.6	0.34	-	-	0.76	5.9	32.2	-	1.3	9.1	4.5
92	IL-92	3.15	-0.24	83.5	1.0	132.6	0.45	-	-	0.71	14.1	27.7	-	3.3	13.8	2.3
93	IL-93	1.05	47.60	85.6	0.3	102.6	0.31	-	-	0.75	37.2	19.3	-	1.3	10.7	3.5
94	IL-94	0.60	74.56	86.3	0.5	97.5	0.36	-	-	0.96	17.6	43.5	-	2.3	7.2	4.5
95	IL-95	0.64	71.00	86.3	.	104.8	0.43	-	-	0.75	3.1	16.2	-	1.0	9.6	5.0
96	IL-96	0.68	71.52	83.5	1.4	114.9	0.31	-	-	0.37	1.0	35.9	-	1.0	9.3	2.7
97	IL-97	1.34	26.55	79.5	5.1	122.6	0.40	-	-	0.84	20.2	27.5	-	1.5	13.2	3.7
98	IL-98	1.37	28.12	80.3	1.8	130.1	0.37	-	-	0.85	52.5	28.3	-	1.1	12.1	3.8
99	IL-99	1.08	50.42	78.0	0.6	127.1	0.35	-	-	0.63	16.6	29.0	-	1.0	14.1	4.7
100	IL-100	1.33	30.94	87.9	.	124.0	0.38	-	-	0.95	8.2	24.6	-	1.0	14.4	3.8
101	IL-101	1.31	39.17	84.0	0.9	103.9	0.42	-	-	0.92	5.2	24.0	-	1.2	13.8	4.0
102	IL-102	2.17	20.05	84.3	0.2	123.9	0.37	-	-	1.02	2.5	30.2	-	1.2	13.7	3.5
103	IL-103	2.16	9.27	82.9	3.2	136.8	0.39	-	-	1.20	7.4	37.3	-	0.9	9.8	3.0
104	IL-104	0.90	57.14	86.3	0.5	92.5	0.38	-	-	0.83	54.2	21.0	-	1.0	12.0	4.5
105	IL-105	0.52	79.09	88.3	-0.1	115.5	0.36	-	-	0.38	3.8	38.4	-	1.1	11.1	3.5
106	IL-106	0.40	81.00	83.3	3.0	105.6	0.36	-	-	0.77	12.8	39.1	-	1.5	9.9	4.5
107	IL-107	2.04	10.00	78.3	0.1	141.9	0.36	-	-	0.92	13.9	22.7	-	1.9	11.1	3.0
108	IL-108	1.99	10.93	76.2	1.5	110.0	0.44	-	-	1.09	68.6	17.7	-	2.2	9.8	3.2
Mean		**1.02**	**54.38**	**81.2**	**2.2**	**117.6**	**0.37**	**-**	**-**	**0.71**	**16.9**	**38.4**	**-**	**1.4**	**10.8**	**3.9**
LSD		**0.92**	**47.28**	**4.5**	**3.3**	**37.2**	**0.11**	**-**	**-**	**0.46**	**31.9**	**31.2**	**-**	**0.9**	**4.8**	**1.2**
MSe		**0.23**	**587.55**	**4.5**	**2.0**	**356.9**	**0.00**	**-**	**-**	**0.05**	**275.9**	**208.8**	**-**	**0.2**	**6.1**	**0.4**
CV		**46.98**	**44.58**	**2.6**	**63.0**	**16.1**	**15.17**	**-**	**-**	**32.17**	**98.3**	**37.6**	**-**	**30.9**	**23.0**	**15.5**
p		**0.000**	**0.000**	**0.000**	**0.001**	**0.024**	**0.048**	**-**	**-**	**0.019**	**0.000**	**0.000**	**-**	**0.000**	**0.000**	**0.000**
Min		**0.09**	**-0.24**	**75.5**	**-0.3**	**84.6**	**0.28**	**-**	**-**	**0.22**	**-5.6**	**13.4**	**-**	**0.9**	**4.2**	**1.5**
Max		**3.15**	**103.47**	**88.3**	**8.4**	**170.0**	**0.49**	**-**	**-**	**1.22**	**69.3**	**113.5**	**-**	**3.3**	**14.4**	**5.0**

(2-2.e) Chókwè random drought

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Husk Cover	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
1	IL-1	1.72	11.09	63.4	8.5	-	-	-	10.2	1.39	21.8	8.5	1.6	12.8	3.2
2	IL-2	1.17	58.31	64.2	9.1	-	-	-	28.6	1.15	53.9	9.0	1.4	15.0	3.0
3	IL-3	0.84	85.32	66.5	7.6	-	-	-	56.2	1.03	30.3	7.2	0.8	13.7	4.1
4	IL-4	1.70	19.07	65.6	5.7	-	-	-	50.8	0.82	48.9	9.0	1.0	15.0	3.0
5	IL-5	1.36	44.02	65.9	7.0	-	-	-	45.4	1.17	55.1	7.9	0.9	13.8	3.0
6	IL-6	0.98	77.34	64.7	8.5	-	-	-	37.8	1.10	11.6	8.6	1.0	13.2	3.8
7	IL-7	1.54	29.49	63.6	7.0	-	-	-	25.3	1.26	78.0	8.3	1.0	14.5	3.3
8	IL-8	1.56	27.83	64.0	8.5	-	-	-	37.5	1.23	44.9	8.0	1.1	13.4	3.6
9	IL-9	1.58	23.80	66.8	5.9	-	-	-	79.9	1.23	46.3	9.0	2.2	14.8	2.7
10	IL-10	1.68	13.91	64.6	8.1	-	-	-	43.2	1.11	21.1	7.8	1.0	17.4	2.8
11	IL-11	1.37	41.80	62.9	5.9	-	-	-	38.9	1.00	41.1	8.6	0.9	15.4	3.8
12	IL-12	0.75	89.16	68.6	6.0	-	-	-	47.7	1.16	41.2	8.3	1.8	13.9	3.7
13	IL-13	1.63	19.73	66.1	9.1	-	-	-	9.1	1.12	30.7	8.9	1.2	15.1	3.2
14	IL-14	1.04	71.00	72.1	7.4	-	-	-	33.1	0.97	32.1	9.0	1.0	13.9	3.2
15	IL-15	1.21	50.48	63.3	8.6	-	-	-	19.2	1.04	71.1	8.1	1.6	14.4	3.6
16	IL-16	1.85	8.64	65.2	10.6	-	-	-	18.0	1.05	34.6	8.5	1.0	15.7	2.1
17	IL-17	1.67	16.10	65.1	8.9	-	-	-	25.5	0.96	13.7	8.6	1.7	15.2	2.9
18	IL-18	1.07	65.21	65.3	8.6	-	-	-	49.0	1.49	24.4	9.0	2.1	16.6	3.9
19	IL-19	0.73	90.31	66.6	7.5	-	-	-	40.9	1.01	20.3	8.9	2.1	13.7	3.0
20	IL-20	1.59	30.63	66.1	7.5	-	-	-	43.4	1.03	62.4	8.0	1.2	12.4	2.7
21	IL-21	0.79	87.80	65.4	8.3	-	-	-	23.8	0.92	82.4	9.0	1.8	14.0	4.0
22	IL-22	1.43	35.57	63.2	4.7	-	-	-	34.0	0.95	20.7	9.1		17.1	3.0
23	IL-23	1.32	42.35	63.6	9.0	-	-	-	6.0	1.13	53.0	8.7	1.0	13.4	2.7
24	IL-24	1.24	53.26	67.7	7.4	-	-	-	55.1	1.13	27.3	7.7	1.1	13.4	3.4
25	IL-25	1.07	68.50	64.2	9.9	-	-	-	15.5	1.26	21.6	8.5	0.9	14.5	3.5
26	IL-26	0.71	90.88	71.9	8.4	-	-	-	18.9	0.91	26.6	8.3	1.0	13.1	3.4
27	IL-27	1.21	57.40	66.2	7.4	-	-	-	32.2	1.01	23.4	8.2	1.9	13.9	3.6
28	IL-28	0.94	79.13	70.7	5.0	-	-	-	11.8	0.88	25.0	8.5	1.2	12.4	3.4

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Husk	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Cover	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
29	IL-29	1.13	58.36	65.7	3.5	-	-	-	66.3	1.02	29.6	9.0	1.5	16.5	3.6
30	IL-30	1.02	68.63	66.1	7.9	-	-	-	47.9	1.23	47.9	9.1	1.0	15.5	3.8
31	IL-31	1.44	35.35	64.3	6.0	-	-	-	31.2	1.08	24.6	8.5	2.3	15.2	2.9
32	IL-32	0.50	102.74	64.6	9.4	-	-	-	2.7	0.72	28.1	8.6	1.0	15.0	3.7
33	IL-33	1.76	9.72	62.2	4.5	-	-	-	20.4	1.26	6.1	7.7	1.4	15.4	3.0
34	IL-34	1.67	14.81	64.3	4.0	-	-	-	35.4	0.85	10.2	8.6	1.0	14.1	1.9
35	IL-35	1.61	25.75	64.8	4.4	-	-	-	38.2	1.13	83.5	8.4	1.0	14.9	3.4
36	IL-36	1.61	27.36	62.6	5.8	-	-	-	4.5	1.23	51.4	9.0	1.3	14.5	3.7
37	IL-37	0.62	96.70	62.1	8.5	-	-	-	38.0	0.86	34.8	8.9	0.9	13.8	4.2
38	IL-38	1.19	58.25	64.8	8.5	-	-	-	6.3	1.08	45.0	8.4	1.8	15.2	3.6
39	IL-39	1.03	71.09	71.4	8.0	-	-	-	19.2	0.86	34.1	9.0	2.2	16.9	3.3
40	IL-40	1.33	44.82	64.4	6.5	-	-	-	36.8	0.94	78.4	8.1	1.2	17.1	3.4
41	IL-41	1.07	68.34	60.9	9.0	-	-	-	40.6	0.89	39.9	8.5	1.4	15.0	3.2
42	IL-42	1.17	56.32	64.9	8.1	-	-	-	13.5	1.15	35.2	9.1	1.8	15.3	3.6
43	IL-43	1.66	16.59	66.2	4.6	-	-	-	6.7	1.08	34.1	8.2	2.8	14.4	3.1
44	IL-44	1.73	11.13	64.6	4.3	-	-	-	45.7	1.12	-0.1	8.9	1.4	16.5	2.7
45	IL-45	0.81	86.17	65.9	8.3	-	-	-	74.3	0.85	34.3	8.3	1.1	14.1	3.5
46	IL-46	1.40	35.63	64.0	9.2	-	-	-	19.4	1.36	34.2	8.4	1.0	15.8	3.4
47	IL-47	1.53	25.33	63.6	7.1	-	-	-	44.6	1.14	22.3	8.1	2.1	15.8	3.2
48	IL-48	1.30	44.84	64.8	8.5	-	-	-	17.7	1.27	31.8	8.9	0.8	13.4	3.5
49	IL-49	1.47	33.37	64.8	6.5	-	-	-	43.9	1.15	40.9	7.8	1.3	14.6	3.7
50	IL-50	0.98	76.16	69.7	9.5	-	-	-	51.2	1.09	37.2	7.5	1.2	14.7	3.7
51	IL-51	1.08	62.98	61.7	8.0	-	-	-	72.0	1.43	92.1	8.0	1.5	12.8	3.4
52	IL-52	0.96	73.92	64.9	8.5	-	-	-	26.5	1.11	24.4	8.4	0.9	12.4	3.4
53	IL-53	1.91	3.22	63.9	4.5	-	-	-	36.5	1.16	17.6	8.6	1.7	14.8	2.6
54	IL-54	1.29	47.22	63.3	5.6	-	-	-	22.3	1.27	45.0	8.5	1.0	14.4	2.9
55	IL-55	1.43	33.50	62.8	4.9	-	-	-	50.2	0.99	32.8	7.7	2.5	16.7	3.2
56	IL-56	0.95	77.60	66.5	7.5	-	-	-	47.2	0.98	3.1	8.4	1.4	13.2	3.0
57	IL-57	1.31	42.57	64.7	7.4	-	-	-	11.0	1.64	94.4	8.6	1.3	13.8	4.2
58	IL-58	1.13	63.03	64.2	8.3	-	-	-	45.5	1.13	8.7	8.1	1.2	15.3	3.5

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Husk	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Cover	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
59	IL-59	1.32	46.75	65.8	6.6	-	-	-	27.2	1.15	55.4	8.5	1.1	15.0	3.8
60	IL-60	1.32	43.31	72.7	5.6	-	-	-	16.2	1.08	86.4	8.6	1.4	14.9	4.0
61	IL-61	0.62	95.07	65.3	7.6	-	-	-	29.4	1.12	24.0	9.0	1.0	15.6	3.9
62	IL-62	1.50	29.04	64.0	5.4	-	-	-	40.7	1.27	78.1	8.5	1.0	15.1	3.5
63	IL-63	1.29	47.23	70.6	6.6	-	-	-	15.0	0.99	63.4	8.5	1.0	14.0	4.2
64	IL-64	1.71	20.55	65.2	3.1	-	-	-	4.7	1.45	17.7	9.0	1.6	14.6	3.3
65	IL-65	0.92	79.29	65.0	8.8	-	-	-	43.8	0.80	61.9	7.7	1.0	14.9	3.8
66	IL-66	1.17	55.88	64.6	8.6	-	-	-	21.8	1.31	37.8	8.2	1.8	15.2	3.3
67	IL-67	0.74	85.10	71.4	8.9	-	-	-	19.7	0.95	54.2	9.0	1.0	16.0	3.6
68	IL-68	1.61	23.91	64.8	3.6	-	-	-	61.0	0.97	21.9	7.9	1.1	15.5	2.7
69	IL-69	1.63	20.99	66.1	4.4	-	-	-	32.3	1.32	15.2	8.5	1.0	16.0	3.4
70	IL-70	0.99	73.53	66.2	8.0	-	-	-	31.8	1.13	36.9	7.7	1.5	14.3	3.9
71	IL-71	1.75	14.30	62.0	7.0	-	-	-	19.8	0.95	51.1	8.2	1.9	16.8	3.0
72	IL-72	1.57	23.14	62.5	6.1	-	-	-	11.5	0.94	38.7	8.4	1.3	15.1	3.2
73	IL-73	1.35	45.11	64.3	8.8	-	-	-	31.9	1.15	30.4	9.0	1.5	15.4	3.3
74	IL-74	1.24	50.89	65.0	8.6	-	-	-	63.5	1.22	9.4	9.0	2.0	12.0	3.1
75	IL-75	1.53	28.28	60.6	5.4	-	-	-	16.2	1.15	8.0	8.6	1.0	12.7	2.8
76	IL-76	1.75	10.29	63.1	5.6	-	-	-	10.4	1.45	47.6	8.0	0.9	12.9	3.0
77	IL-77	1.57	21.64	60.8	5.6	-	-	-	48.2	1.16	90.8	8.4	1.4	14.1	3.7
78	IL-78	1.18	55.95	61.6	9.6	-	-	-	58.5	0.98	15.8	8.5	1.6	14.5	3.9
79	IL-79	0.93	79.79	72.3	8.5	-	-	-	14.2	0.97	20.0	9.1	2.1	14.8	3.4
80	IL-80	1.43	34.55	66.1	5.6	-	-	-	6.9	1.17	55.9	7.4	1.0	15.6	3.9
81	IL-81	1.73	11.28	71.6	4.5	-	-	-	6.4	1.15	31.7	8.5	2.9	14.9	3.7
82	IL-82	1.11	62.68	65.1	6.5	-	-	-	21.8	1.28	11.5	8.2	0.9	14.5	3.9
83	IL-83	0.46	100.32	73.6	9.0	-	-	-	30.4	0.72	2.7	7.8	2.4	18.1	4.6
84	IL-84	1.19	53.14	72.8	8.6	-	-	-	31.5	1.34	41.5	9.1	2.5	14.9	3.0
85	IL-85	0.80	87.16	72.7	8.4	-	-	-	4.8	1.10	13.8	9.0	2.7	9.6	3.0
86	IL-86	1.26	51.06	71.4	5.7	-	-	-	19.7	0.94	14.5	8.4	3.6	13.7	2.7
87	IL-87	0.94	79.62	72.6	9.0	-	-	-	22.9	1.31	31.9	8.4	1.9	15.3	3.9
88	IL-88	0.79	88.32	72.1	8.6	-	-	-	11.9	1.07	17.5	5.1	2.2	13.9	4.0

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Husk Cover	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
89	IL-89	1.24	50.85	70.2	6.9	-	-	-	49.5	1.32	13.9	8.2	0.8	13.9	3.1
90	IL-90	1.77	8.85	65.5	4.7	-	-	-	28.0	1.29	40.0	8.5	2.2	15.0	4.0
91	IL-91	0.81	85.15	69.9	10.0	-	-	-	87.1	0.78	29.0	8.5	2.2	19.4	3.9
92	IL-92	2.31	-7.37	63.3	5.2	-	-	-	8.3	1.39	50.9	8.4	3.0	12.8	1.9
93	IL-93	1.46	31.98	72.5	4.5	-	-	-	32.3	1.29	83.4	8.4	1.4	14.0	4.1
94	IL-94	0.87	84.70	71.4	9.1	-	-	-	11.9	0.87	78.3	7.9	2.8	19.1	4.0
95	IL-95	0.26	102.43	72.7		-	-	-	4.1	0.63	3.4	8.5	1.6	12.0	4.8
96	IL-96	1.93	11.30	69.9	6.0	-	-	-	18.3	1.27	30.7	8.3	1.1	13.1	2.5
97	IL-97	1.40	40.32	70.9	6.5	-	-	-	32.9	0.91	35.1	8.5	1.8	14.7	3.0
98	IL-98	1.59	24.43	65.2	4.3	-	-	-	30.2	1.30	95.9	8.6	0.8	13.6	3.3
99	IL-99	1.51	26.57	64.6	4.5	-	-	-	18.3	1.08	15.4	7.3	0.9	16.0	2.0
100	IL-100	1.70	13.44	64.9	5.1	-	-	-	5.5	1.57	25.9	9.0	1.2	15.5	3.1
101	IL-101	1.83	4.84	65.2	6.1	-	-	-	10.4	1.66	7.9	8.7	1.2	15.6	2.3
102	IL-102	2.01	0.86	65.1	4.4	-	-	-	27.4	1.68	14.3	9.0	1.0	14.6	3.0
103	IL-103	1.76	15.66	64.6	7.0	-	-	-	13.0	1.39	35.6	8.5		14.9	3.2
104	IL-104	1.06	67.31	71.8	7.9	-	-	-	63.2	1.04	45.6	9.1	1.6	16.9	3.1
105	IL-105	1.56	24.07	65.0	6.5	-	-	-	45.6	1.01	4.9	8.5	1.1	18.8	2.5
106	IL-106	1.08	63.27	65.1	8.2	-	-	-	19.2	1.20	50.2	9.0	1.4	15.1	3.3
107	IL-107	1.70	21.73	64.3	5.6	-	-	-	21.9	1.27	16.2	8.5	1.1	13.6	3.2
108	IL-108	1.19	55.13	73.3	6.0	-	-	-	46.5	1.02	101.5	8.5	2.7	15.0	3.8
Mean		**1.30**	**47.25**	**66.2**	**7.0**	**-**	**-**	**-**	**30.6**	**1.12**	**37.3**	**8.4**	**1.5**	**14.7**	**3.3**
p		**0.52**	**38.02**	**1.9**	**1.6**	**-**	**-**	**-**	**32.0**	**0.36**	**39.6**	**1.4**	**1.0**	**3.4**	**0.9**
MSe		**0.07**	**360.37**	**0.9**	**0.7**	**-**	**-**	**-**	**273.4**	**0.03**	**410.5**	**0.5**	**0.3**	**3.1**	**0.2**
CV		**19.85**	**40.17**	**1.4**	**11.5**	**-**	**-**	**-**	**54.1**	**16.49**	**54.3**	**8.3**	**36.1**	**11.9**	**14.1**
p		**0.000**	**0.000**	**0.000**	**0.000**	**-**	**-**	**-**	**0.000**	**0.000**	**0.000**	**0.125**	**0.000**	**0.022**	**0.000**
Min		**0.26**	**-7.37**	**60.6**	**3.1**	**-**	**-**	**-**	**2.7**	**0.63**	**-0.1**	**5.1**	**0.8**	**9.6**	**1.9**
Max		**2.31**	**102.74**	**73.6**	**10.6**	**-**	**-**	**-**	**87.1**	**1.68**	**101.5**	**9.1**	**3.6**	**19.4**	**4.8**

(2-2.f) Chókwè unstressed

Entry	Genotype Code	Grain Yield		Anth Date	ASI	Plant Height	Ear Position	Lodging		Ears/ Plant	Husk Cover	Leaf Senes	Grain Text	Num Plants	Ear Aspect
		GW	Rank					Root	Stem						
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
1	IL-1	3.97	24.32	52.4	2.5	231.6	0.52	-	-	1.28	31.2	9.2	1.0	17.0	3.3
2	IL-2	3.33	41.31	52.7	5.1	198.4	0.54	-	-	1.08	53.0	9.2	1.3	16.3	3.1
3	IL-3	2.31	78.85	54.9	3.0	214.4	0.62	-	-	1.37	23.2	10.1	1.1	14.2	2.8
4	IL-4	3.90	22.91	56.5	-0.4	190.7	0.63	-	-	1.17	32.2	9.5	1.2	14.3	3.3
5	IL-5	2.86	56.60	53.3	3.1	185.4	0.63	-	-	1.16	13.3	9.8	1.0	14.3	3.7
6	IL-6	2.51	71.58	54.5	2.0	181.8	0.48	-	-	0.86	17.7	10.0	1.2	18.8	3.8
7	IL-7	3.55	32.70	54.1	3.0	180.8	0.52	-	-	1.20	44.5	9.7	1.1	14.4	3.7
8	IL-8	2.56	66.43	54.0	2.5	187.2	0.54	-	-	1.12	38.7	9.8	3.8	14.9	4.8
9	IL-9	3.99	23.23	48.4	2.6	196.5	0.60	-	-	1.11	56.0	8.0	2.5	14.7	3.0
10	IL-10	4.63	4.60	54.7	2.6	187.5	0.61	-	-	1.38	26.0	9.2	1.0	16.0	2.8
11	IL-11	2.78	61.35	55.0	2.0	183.8	0.65	-	-	1.19	62.1	10.1	1.0	17.9	3.9
12	IL-12	1.72	89.45	57.9	3.5	180.9	0.49	-	-	1.34	37.9	9.5	1.0	14.2	4.0
13	IL-13	2.48	64.45	56.7	3.6	203.8	0.51	-	-	1.19	103.3	8.3	1.5	16.3	4.0
14	IL-14	2.63	65.61	60.4	1.5	165.1	0.57	-	-	0.94	39.1	9.9	1.1	15.0	3.5
15	IL-15	2.59	69.01	57.5	2.0	179.0	0.55	-	-	0.98	6.0	9.8	1.0	13.9	3.4
16	IL-16	1.69	95.74	55.4	3.0	225.1	0.59	-	-	1.08	14.2	8.8	1.0	15.6	2.8
17	IL-17	4.14	18.61	55.8	0.4	186.4	0.66	-	-	1.16	12.5	8.7	1.2	13.9	2.4
18	IL-18	2.57	69.13	56.3	0.5	191.7	0.53	-	-	1.64	6.0	10.2	2.5	15.3	4.7
19	IL-19	2.39	77.89	58.8	1.6	190.1	0.51	-	-	1.07	50.2	9.4	1.2	14.3	4.6
20	IL-20	4.29	7.37	55.6	2.6	174.3	0.50	-	-	1.30	29.8	4.5	1.0	14.4	2.7
21	IL-21	2.72	62.65	54.3	2.7	211.7	0.57	-	-	1.06	82.8	9.5	1.6	17.7	4.9
22	IL-22	3.75	28.30	53.9	1.9	193.6	0.43	-	-	1.34	11.6	9.4	2.1	15.5	3.6
23	IL-23	3.85	28.15	54.9	2.6	193.2	0.50	-	-	1.36	49.0	9.2	2.2	16.1	5.0
24	IL-24	3.21	45.00	57.2	3.0	174.1	0.54	-	-	1.17	11.8	8.2	1.1	15.6	3.0
25	IL-25	1.59	89.58	55.0	4.0	209.6	0.49	-	-	0.85	17.6	10.0	1.1	15.5	4.1
26	IL-26	1.53	93.86	61.8	2.4	210.8	0.58	-	-	0.75	18.8	8.8	1.0	12.7	3.5
27	IL-27	4.25	16.16	55.3	3.1	204.6	0.51	-	-	1.13	53.5	8.1	1.1	15.1	3.7
28	IL-28	1.67	90.43	56.8	2.0	198.3	0.49	-	-	1.05	28.1	9.5	2.3	12.5	4.2

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Husk	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Cover	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
29	IL-29	3.62	32.97	53.6	2.2	207.5	0.58	-	-	1.26	14.7	9.8	1.5	20.3	3.5
30	IL-30	2.44	78.17	56.8	2.6	194.0	0.53	-	-	0.96	47.9	9.6	1.3	16.1	3.4
31	IL-31	4.57	23.58	56.2	2.6	180.8	0.57	-	-	1.08	9.1	3.8	2.8	18.2	2.3
32	IL-32	1.86	95.25	56.3	2.0	179.4	0.57	-	-	0.88	37.9	7.5	1.7	15.2	3.8
33	IL-33	4.17	15.98	53.8	3.1	186.7	0.58	-	-	1.17	27.2	9.2	1.2	14.8	2.6
34	IL-34	2.99	52.98	55.0	3.0	197.9	0.55	-	-	1.00	4.8	8.8	1.0	13.3	2.4
35	IL-35	2.69	65.57	55.0	2.4	180.9	0.60	-	-	1.12	69.0	8.2	1.0	13.3	3.7
36	IL-36	2.94	55.08	54.0	2.6	189.2	0.56	-	-	1.11	92.5	8.1	1.0	16.1	3.9
37	IL-37	2.28	84.53	50.5	2.0	187.2	0.53	-	-	1.27	52.6	10.1	1.0	15.0	3.8
38	IL-38	4.53	8.83	54.4	3.0	200.6	0.56	-	-	1.34	46.2	7.3	1.3	17.2	3.4
39	IL-39	1.83	98.07	59.9	4.1	188.9	0.55	-	-	1.24	35.2	10.0	1.0	14.8	3.7
40	IL-40	3.28	40.36	51.9	2.9	168.6	0.58	-	-	1.18	109.7	6.0	0.9	13.2	3.9
41	IL-41	1.67	93.13	54.4	3.0	184.3	0.54	-	-	0.96	26.0	9.6	1.5	15.3	3.7
42	IL-42	2.43	75.33	53.5	2.5	185.6	0.60	-	-	1.18	22.5	9.6	1.1	15.3	3.8
43	IL-43	3.61	35.58	55.8	2.5	205.1	0.55	-	-	1.23	23.0	9.4	2.2	15.5	3.7
44	IL-44	3.37	39.37	55.9	0.9	191.6	0.68	-	-	1.01	9.2	8.1	1.5	18.6	2.4
45	IL-45	2.69	66.02	55.4	2.4	195.6	0.63	-	-	1.00	13.7	9.3	1.2	15.2	3.8
46	IL-46	4.23	15.40	55.7	1.5	204.9	0.54	-	-	1.43	26.0	9.2	1.4	16.2	3.7
47	IL-47	5.12	4.23	54.4	3.3	214.4	0.57	-	-	1.47	15.2	8.3	1.7	15.4	2.6
48	IL-48	2.73	68.82	56.9	0.3	209.0	0.63	-	-	0.91	12.7	9.3	1.5	13.4	3.6
49	IL-49	2.98	52.74	55.4	1.0	166.8	0.59	-	-	1.11	22.0	9.8	2.9	17.1	4.2
50	IL-50	2.37	74.06	56.9	-0.1	185.9	0.54	-	-	1.21	12.4	9.8	1.3	15.7	3.4
51	IL-51	3.58	33.99	52.9	2.6	175.8	0.62	-	-	1.07	74.1	10.1	1.8	19.1	5.0
52	IL-52	2.94	58.68	55.8	1.8	194.6	0.55	-	-	1.24	13.8	9.3	1.1	13.4	3.6
53	IL-53	6.09	-6.32	48.9	1.9	211.4	0.55	-	-	1.19	37.0	7.6	1.8	19.5	2.3
54	IL-54	4.48	6.47	51.7	3.2	215.0	0.50	-	-	1.13	40.5	9.5	1.8	19.2	3.3
55	IL-55	3.69	25.80	55.1	3.0	192.1	0.57	-	-	1.13	65.5	9.6	1.5	17.6	3.8
56	IL-56	1.56	98.15	58.0	0.5	224.0	0.55	-	-	1.05	-2.6	10.1	1.2	13.4	3.4
57	IL-57	2.56	78.42	57.7	1.9	202.3	0.51	-	-	1.51	66.3	6.1	1.5	16.0	4.3
58	IL-58	2.00	91.58	54.5	2.9	182.8	0.55	-	-	0.95	14.7	9.1	1.0	15.5	4.0

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Husk	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Cover	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
59	IL-59	3.02	54.71	56.0	1.9	183.7	0.62	-	-	1.11	55.1	5.2	0.9	15.0	3.9
60	IL-60	2.31	76.87	61.0	3.4	174.1	0.71	-	-	1.01	85.1	5.8	1.5	16.9	4.5
61	IL-61	1.29	107.65	55.7	1.9	185.9	0.53	-	-	1.27	4.0	8.9	1.0	15.1	3.9
62	IL-62	3.23	44.73	54.4	2.5	226.3	0.54	-	-	1.24	102.4	8.3	1.1	15.2	3.4
63	IL-63	2.12	82.06	61.5	2.8	149.3	0.54	-	-	1.06	74.7	5.0	1.1	14.8	4.9
64	IL-64	2.93	57.86	53.8	2.0	224.9	0.62	-	-	1.15	5.0	9.8	1.9	21.8	4.0
65	IL-65	2.03	84.37	55.2	2.0	214.1	0.50	-	-	0.95	49.7	8.5	1.0	16.6	3.7
66	IL-66	2.42	72.82	55.6	3.1	190.3	0.57	-	-	1.21	38.7	8.6	1.1	15.4	3.1
67	IL-67	1.24	101.79	61.3	3.1	197.9	0.66	-	-	0.84	29.3	3.2	1.0	14.9	4.3
68	IL-68	2.83	58.04	56.1	1.3	185.6	0.53	-	-	0.92	36.3	9.0	1.0	15.8	3.2
69	IL-69	2.99	53.16	58.8	0.5	212.5	0.55	-	-	1.47	37.5	7.6	1.1	15.0	3.1
70	IL-70	2.19	81.63	55.6	3.4	180.6	0.53	-	-	0.93	31.7	8.6	1.5	14.8	3.7
71	IL-71	4.12	14.50	58.6	-0.9	238.1	0.53	-	-	1.27	65.2	9.4	1.7	14.9	3.6
72	IL-72	3.13	47.64	53.4	4.6	179.6	0.58	-	-	1.10	34.8	9.1	1.1	15.5	3.3
73	IL-73	4.02	21.22	54.7	3.0	194.3	0.58	-	-	1.33	15.7	8.8	1.3	15.3	3.4
74	IL-74	2.52	70.71	54.8	3.7	193.0	0.60	-	-	1.04	36.3	9.8	1.5	15.2	3.9
75	IL-75	3.94	16.44	52.8	1.1	199.3	0.55	-	-	1.20	34.0	9.6	1.0	15.0	2.9
76	IL-76	4.01	26.52	52.6	3.4	206.7	0.53	-	-	0.93	50.5	6.7	1.5	18.2	2.9
77	IL-77	3.72	30.74	48.8	1.7	219.9	0.57	-	-	1.48	55.7	8.4	1.3	13.2	4.1
78	IL-78	3.55	39.72	54.4	2.5	180.6	0.54	-	-	1.22	10.7	9.9	0.9	18.6	3.2
79	IL-79	2.85	58.89	55.0	0.9	188.1	0.54	-	-	1.25	20.6	8.3	2.1	16.5	4.0
80	IL-80	3.16	50.39	56.9	4.6	209.6	0.59	-	-	1.38	71.4	6.0	1.6	15.5	4.2
81	IL-81	2.08	83.88	62.0	2.5	209.5	0.55	-	-	1.18	38.9	7.3	1.8	13.8	4.5
82	IL-82	3.21	41.31	54.6	1.5	190.6	0.56	-	-	1.40	-11.5	7.4	0.9	13.4	3.1
83	IL-83	1.47	93.66	63.6	3.4	181.3	0.62	-	-	0.90	-10.0	2.4	2.9	13.7	4.3
84	IL-84	1.44	91.21	62.9	3.0	157.3	0.60	-	-	1.10	26.9	1.4	3.7	15.9	4.5
85	IL-85	1.89	94.83	62.0	2.4	203.7	0.60	-	-	1.00	2.1	3.9	2.6	15.6	4.1
86	IL-86	2.52	71.51	56.8	-2.0	211.4	0.54	-	-	0.99	13.9	5.1	3.7	13.6	4.6
87	IL-87	3.04	50.53	62.5	2.4	167.1	0.53	-	-	1.75	5.3	2.4	2.5	14.8	3.6
88	IL-88	3.05	52.93	61.7	2.4	224.7	0.46	-	-	0.99	3.8	8.6	2.8	13.7	3.4

Entry	Genotype	Grain Yield		Anth	ASI	Plant	Ear	Lodging		Ears/	Husk	Leaf	Grain	Num	Ear
	Code	GW	Rank	Date		Height	Position	Root	Stem	Plant	Cover	Senes	Text	Plants	Aspect
		t/ha	Rank	d	d	cm	0-1	%	%	#	%	1-10	1-5	#	1-5
89	IL-89	3.35	42.67	58.7	1.0	171.2	0.59	-	-	1.22	7.7	7.2	1.5	15.1	3.7
90	IL-90	3.09	48.21	56.5	2.1	157.9	0.57	-	-	1.33	11.3	8.9	1.0	13.7	2.6
91	IL-91	2.61	64.35	63.9	-0.9	182.1	0.59	-	-	0.97	38.6	10.0	1.5	15.5	3.6
92	IL-92	5.98	2.80	60.2	3.5	216.7	0.59	-	-	1.14	27.0	4.6	2.9	19.0	2.8
93	IL-93	2.54	73.79	61.8	2.1	176.0	0.52	-	-	1.27	49.2	5.1	1.8	14.4	4.1
94	IL-94	2.93	55.47	62.2	1.9	178.7	0.50	-	-	1.07	59.9	5.5	2.8	21.1	4.7
95	IL-95	0.30	106.70	63.0	2.0	140.6	0.60	-	-	0.37	5.8	7.5	1.0	15.3	4.5
96	IL-96	2.12	86.01	57.1	-0.1	170.1	0.57	-	-	1.05	1.2	6.6	0.9	15.6	2.5
97	IL-97	3.63	27.90	56.4	2.4	211.8	0.60	-	-	1.16	28.0	7.4	1.4	16.0	3.8
98	IL-98	3.28	46.50	55.3	1.7	201.4	0.59	-	-	1.06	26.6	9.6	1.0	15.7	2.6
99	IL-99	2.79	56.48	52.4	4.1	189.5	0.57	-	-	1.01	44.6	8.8	0.9	14.4	3.5
100	IL-100	4.01	23.26	55.8	2.7	195.6	0.57	-	-	1.76	41.3	8.7	1.3	15.6	4.0
101	IL-101	4.97	3.57	57.0	-2.0	199.2	0.55	-	-	1.43	-0.8	7.8	1.2	18.4	3.1
102	IL-102	4.70	5.76	54.4	2.3	203.8	0.51	-	-	1.53	23.4	8.6	1.0	16.3	3.2
103	IL-103	3.51	34.75	58.0	4.4	221.7	0.55	-	-	1.49	20.3	7.8	1.6	14.0	3.5
104	IL-104	2.53	71.72	62.0	2.0	189.4	0.50	-	-	1.14	82.4	8.3	1.3	18.3	3.7
105	IL-105	3.79	32.24	58.9	2.5	192.6	0.48	-	-	1.01	7.8	8.8	1.1	19.8	2.7
106	IL-106	2.85	66.32	55.3	3.5	208.5	0.60	-	-	1.67	17.8	9.8	1.6	14.8	4.0
107	IL-107	4.53	1.93	55.3	2.9	182.4	0.52	-	-	1.54	72.3	9.6	3.0	16.7	3.1
108	IL-108	4.20	25.30	56.8	0.1	180.3	0.50	-	-	1.33	105.4	10.1	2.2	15.6	4.5
Mean		**3.04**	**53.39**	**56.2**	**2.2**	**193.4**	**0.56**			**1.17**	**34.2**	**8.3**	**1.5**	**15.7**	**3.6**
LSD		**1.12**	**33.96**	**2.2**	**1.9**	**32.9**	**0.10**			**0.31**	**26.6**	**0.9**	**0.6**	**4.0**	**1.2**
MSe		**0.40**	**343.73**	**1.3**	**0.9**	**276.0**	**0.00**			**0.02**	**213.6**	**0.2**	**0.1**	**4.0**	**0.4**
CV		**20.78**	**34.73**	**2.0**	**42.1**	**8.6**	**8.80**			**13.52**	**42.7**	**5.7**	**20.4**	**12.8**	**17.4**
p		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**			**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**
Min		**0.30**	**-6.32**	**48.4**	**-2.0**	**140.6**	**0.43**			**0.37**	**-11.5**	**1.4**	**0.9**	**12.5**	**2.3**
Max		**6.09**	**107.65**	**63.9**	**5.1**	**238.1**	**0.71**			**1.76**	**109.7**	**10.2**	**3.8**	**21.8**	**5.0**

Appendix 2-3. Results of the combined pre-ANOVA of six experiments conducted under two water-regimes at Chiredzi, Save Valley and Chokwe.

Source	DF	GY	GY-Rank	NP	EPP	EA	AD	ASI	PH	EPO	LS	SL
Location (L)	2	119.550	1.271	456.655	23.633	40.015	4787.567	370.623	200709.330	0.154	2920.840***	311.237
Stress (Location) (S)	1	113.415	5.331	407.035	0.497	22.693	7881.258	1401.819	11348.493	1.304	0.025	4.353
L × S	2	34.188	4.543	288.692	1.197	18.327	14370.611	233.369	40503.253	0.244	2.297	7.760
Genotype (G)	107	1.050***	2975.524***	5.231***	0.0667***	0.736***	53.271***	8.036***	468.967***	0.004	0.696***	0.963***
L × G	214	0.236	599.344	2.668	0.036*	0.244*	7.285***	4.840	173.760	0.003	0.516***	0.172
S × G	107	0.192	537.965	2.205	0.024	0.185	3.831	4.991	184.277	0.003	0.269	0.180
L × S × G	213	0.210	568.085	2.240	0.026	0.184	4.019	4.454	240.271	0.004	0.286	0.178

Appendix 2-4. Best linear unbiased linear estimate means of 108 maize inbred lines evaluated at Chiredzi, Save Valley and Chókwè in 2014.

(2-4.a) Chiredzi - severe heat-drought stress environmental condition

Inbred line	Grain Yield		Anth	ASI	Plant	Ear	Stem	Ears/	Leaf	Num	Ear
code	GW	Rank	Date		Height	Pos.	lodg.	Plant	Sen.	Plants	Aspect
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-31	1.80	14.39	65.7	5.5	151.5	0.54	1.0	0.61	6.1	16.6	3.5
IL-107	1.60	17.47	66.5	0.9	168.2	0.49	4.7	0.48	6.5	15.0	3.3
IL-43	1.36	19.69	70.1	0.7	176.8	0.48	0.5	0.46	6.7	16.4	3.7
IL-108	1.65	21.50	65.1	3.4	169.3	0.53	0.7	0.76	6.3	15.0	3.7
IL-17	1.07	22.85	63.6	3.4	163.5	0.58	2.3	0.59	5.7	16.6	3.9
IL-99	1.38	24.94	66.9	2.0	155.9	0.45	1.6	0.64	6.1	16.3	4.1
IL-101	1.16	25.34	70.3	0.7	171.6	0.46	0.1	0.83	6.2	15.6	3.8
IL-92	1.39	27.85	74.0	1.4	159.7	0.58	-0.5	0.66	5.6	12.6	4.2
IL-76	1.17	29.47	67.1	4.6	160.7	0.58	11.6	0.65	6.6	15.7	4.3
IL-30	1.07	30.09	68.4	3.6	161.9	0.54	1.0	0.65	5.7	15.4	3.9
IL-11	1.23	31.05	65.6	1.3	173.0	0.49	3.7	0.58	5.8	16.3	3.5
IL-10	1.01	33.08	62.2	7.3	146.7	0.61	0.6	0.64	6.6	16.1	3.8
IL-22	1.17	33.97	63.6	5.6	179.7	0.45	6.8	0.53	6.6	14.8	3.5
IL-77	0.95	34.53	64.9	4.4	170.8	0.53	1.5	0.57	6.1	15.8	4.1
IL-105	0.99	34.82	71.2	2.5	174.4	0.49	0.1	0.50	5.9	15.1	3.9
IL-46	0.93	35.93	63.3	-0.2	159.5	0.59	3.2	0.58	7.1	16.7	4.2
IL-16	1.11	36.73	69.6	2.4	165.8	0.52	0.5	0.49	5.8	15.9	4.2
IL-98	0.97	36.99	66.0	2.4	162.0	0.52	1.9	0.77	6.0	15.0	4.2
IL-51	0.91	37.76	62.6	3.0	165.7	0.50	3.2	0.63	6.1	16.6	4.3
IL-53	1.07	38.84	70.2	1.4	153.4	0.58	10.3	0.47	5.5	16.7	4.0
IL-96	0.97	39.72	68.0	2.0	147.5	0.48	0.7	0.79	5.6	13.8	4.1
IL-49	0.91	40.48	60.1	8.4	155.3	0.54	3.7	0.54	6.0	16.6	4.1
IL-64	0.78	41.40	59.3	0.2	181.6	0.53	-1.0	0.58	7.8	16.3	4.1
IL-75	0.97	42.24	69.1	1.2	163.8	0.43	1.4	0.48	6.5	14.9	4.3
IL-47	0.76	42.84	65.0	1.5	151.5	0.50	-1.5	0.56	6.2	16.4	4.3
IL-21	0.76	44.28	68.0	2.7	180.8	0.45	9.2	0.59	6.9	15.1	4.2
IL-19	0.80	44.63	64.6	3.0	138.9	0.46	14.4	0.50	6.7	14.2	4.7
IL-2	0.76	45.14	67.6	3.9	165.3	0.57	14.7	0.49	6.3	15.2	4.0
IL-54	0.80	45.17	62.1	1.5	166.0	0.46	1.9	0.55	6.5	15.0	4.5
IL-85	0.89	45.73	77.1	0.9	174.1	0.50	-0.1	0.69	4.4	15.6	4.7
IL-36	0.83	46.12	65.4	5.0	156.5	0.41	0.8	0.72	5.7	16.6	4.0
IL-38	0.85	46.25	68.9	2.3	150.2	0.48	0.5	0.55	5.7	15.5	4.5
IL-73	1.00	46.40	65.4	3.6	162.9	0.52	1.8	0.61	5.6	15.3	4.1
IL-90	0.83	46.71	67.9	3.8	157.5	0.52	1.2	0.69	6.2	15.0	4.4
IL-1	0.73	48.11	67.3	4.7	174.2	0.49	9.1	0.52	5.3	16.1	4.2
IL-7	0.87	48.59	66.2	2.2	155.1	0.48	3.8	0.54	6.1	14.3	4.3
IL-71	0.74	48.62	64.6	6.5	158.4	0.63	7.8	0.46	7.0	16.4	4.2
IL-62	0.81	49.02	68.1	7.0	161.0	0.46	6.2	0.49	6.6	16.3	4.4

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-86	0.76	50.33	75.8	3.8	188.4	0.45	1.0	0.49	4.7	15.8	4.6
IL-29	0.71	50.48	62.2	2.5	164.7	0.47	1.8	0.51	7.0	15.9	4.4
IL-4	0.77	50.72	62.4	6.1	148.5	0.52	3.7	0.52	5.8	16.7	3.8
IL-23	0.79	50.86	65.2	6.3	167.4	0.51	3.0	0.51	6.5	16.1	4.1
IL-33	0.67	52.17	60.9	8.4	161.4	0.52	2.5	0.60	5.8	16.4	4.3
IL-50	0.68	52.85	70.2	1.0	178.2	0.46	-0.3	0.61	6.4	15.7	4.4
IL-55	0.61	53.83	62.0	2.8	159.1	0.54	1.8	0.45	6.5	16.0	4.2
IL-81	0.85	54.56	70.6	2.5	168.3	0.49	3.8	0.53	6.1	16.1	4.6
IL-100	0.84	55.53	75.3	2.1	166.5	0.54	6.8	0.54	5.6	16.0	4.4
IL-8	0.61	56.48	68.5	2.9	151.7	0.54	7.8	0.57	6.3	15.1	4.7
IL-9	0.93	56.86	66.2	4.1	177.4	0.59	0.3	0.40	5.7	15.9	4.4
IL-103	0.69	57.17	71.4	1.8	180.4	0.54	4.7	0.57	6.0	14.1	4.3
IL-69	0.67	57.52	70.2	0.4	161.9	0.49	10.0	0.53	7.2	16.3	4.1
IL-42	0.53	59.02	68.0	1.8	158.4	0.47	2.9	0.47	6.9	14.9	4.3
IL-13	0.73	59.46	68.9	3.6	170.6	0.45	4.3	0.39	6.2	16.1	4.4
IL-95	0.56	59.53	68.7	-0.5	141.0	0.48	0.8	0.46	7.7	15.1	4.6
IL-20	0.67	59.55	67.8	5.3	150.6	0.55	-2.8	0.68	5.9	14.5	4.1
IL-97	0.62	60.30	70.2	0.6	188.1	0.49	-1.3	0.40	5.7	15.2	4.6
IL-67	0.68	60.37	68.4	1.7	163.3	0.47	-0.9	0.57	6.7	15.4	4.2
IL-84	0.75	60.42	74.0	1.2	160.1	0.57	19.8	0.41	3.5	12.2	4.8
IL-104	0.58	60.96	70.9	2.1	170.1	0.46	0.9	0.49	6.3	16.4	4.5
IL-60	0.66	61.37	69.2	4.1	164.0	0.55	-2.2	0.60	5.3	16.6	4.4
IL-25	0.57	61.68	65.7	4.1	157.6	0.46	5.6	0.61	6.9	15.6	4.5
IL-37	0.52	61.74	61.4	0.2	140.8	0.51	-0.3	0.35	6.6	15.2	4.6
IL-61	0.53	62.10	68.3	4.3	161.2	0.44	-0.8	0.44	6.5	16.1	3.9
IL-82	0.68	62.80	65.7	4.6	148.3	0.52	5.9	0.63	6.2	15.5	4.4
IL-40	0.68	62.89	65.0	3.7	155.0	0.48	5.8	0.69	5.1	15.4	4.5
IL-48	0.60	63.04	70.9	3.3	167.5	0.56	0.8	0.45	6.0	17.1	4.1
IL-35	0.57	63.19	66.0	1.7	151.2	0.44	3.3	0.49	6.3	15.7	4.4
IL-27	0.49	63.70	64.9	5.2	164.4	0.54	3.9	0.53	6.2	15.4	4.5
IL-65	0.49	63.78	64.1	7.2	165.3	0.47	-2.1	0.34	6.9	16.0	4.5
IL-70	0.53	64.00	66.8	3.7	157.2	0.54	2.4	0.55	7.2	15.4	4.6
IL-106	0.62	64.57	65.1	6.7	177.2	0.46	3.0	0.44	6.6	15.9	4.3
IL-80	0.52	64.63	70.5	3.0	161.5	0.53	14.9	0.35	6.2	15.6	4.3
IL-91	0.45	64.70	74.7	0.1	151.2	0.52	2.1	0.59	4.9	15.1	4.7
IL-66	0.46	65.77	63.8	8.3	153.9	0.46	2.6	0.39	7.6	14.8	4.4
IL-34	0.52	65.97	66.3	1.8	163.3	0.46	5.9	0.46	6.3	16.5	4.0
IL-78	0.47	66.03	66.1	4.8	156.2	0.57	5.1	0.40	6.7	16.0	4.2
IL-89	0.49	67.04	71.4	1.8	152.6	0.51	4.0	0.43	5.5	15.6	4.4
IL-39	0.27	67.57	72.7	3.2	173.0	0.59	4.0	0.70	6.5	13.2	4.7
IL-79	0.55	67.89	70.1	1.7	166.8	0.47	3.6	0.41	6.6	16.1	4.8
IL-93	0.48	68.04	73.7	1.5	145.5	0.53	12.1	0.46	4.5	16.0	4.5

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-12	0.54	68.12	70.5	6.6	162.4	0.51	-0.7	0.40	7.3	16.1	4.6
IL-3	0.52	68.18	64.0	4.4	172.0	0.51	1.3	0.43	6.3	15.7	3.6
IL-68	0.55	68.59	65.3	3.7	151.9	0.57	-0.2	0.56	6.7	12.8	4.4
IL-56	0.50	68.72	68.1	6.0	172.0	0.51	5.7	0.50	6.8	15.4	4.6
IL-102	0.55	71.42	73.9	0.8	171.9	0.52	3.2	0.41	6.0	16.2	4.3
IL-45	0.45	71.75	64.6	5.7	164.1	0.52	1.6	0.59	6.9	14.5	4.0
IL-44	0.46	72.44	72.7	0.0	163.2	0.57	9.2	0.42	6.4	15.2	4.4
IL-59	0.45	73.10	70.0	2.2	157.0	0.54	9.4	0.45	5.5	15.9	4.2
IL-74	0.35	73.57	69.0	1.7	167.5	0.46	7.2	0.45	6.0	13.2	4.4
IL-6	0.38	73.78	67.1	4.8	148.7	0.42	2.2	0.56	6.3	15.4	4.2
IL-15	0.50	74.16	61.9	4.7	176.9	0.44	8.9	0.44	7.1	16.1	4.1
IL-72	0.44	74.73	65.2	10.2	164.6	0.47	5.8	0.42	5.7	16.4	4.5
IL-28	0.31	75.61	68.0	3.1	156.3	0.40	6.3	0.38	5.3	14.7	4.6
IL-58	0.31	76.99	65.0	7.3	156.3	0.50	1.3	0.56	7.0	15.0	4.6
IL-57	0.40	77.91	70.5	2.2	147.1	0.62	4.1	0.42	4.6	16.0	4.7
IL-5	0.38	79.11	67.0	3.7	142.9	0.53	4.1	0.36	6.0	16.3	4.7
IL-63	0.36	80.76	66.0	8.1	157.9	0.46	4.0	0.25	5.8	16.5	4.1
IL-32	0.35	80.92	65.7	7.4	160.3	0.47	4.5	0.32	6.2	15.9	4.2
IL-83	0.40	81.85	75.5	0.5	162.1	0.51	4.9	0.40	4.5	13.7	4.5
IL-41	0.41	82.01	64.2	8.1	175.4	0.54	0.8	0.55	5.1	15.3	4.9
IL-88	0.22	82.46	72.5	2.2	170.6	0.51	4.1	0.50	5.4	14.7	4.7
IL-94	0.20	85.27	79.9	-0.9	144.1	0.47	-1.7	0.37	4.8	14.9	4.7
IL-24	0.24	88.21	67.2	11.1	148.9	0.49	1.1	0.38	5.6	15.2	4.9
IL-18	0.31	89.06	60.9	0.8	157.6	0.56	13.0	0.43	7.9	14.4	4.3
IL-52	0.25	90.14	70.0	2.9	160.6	0.54	3.0	0.49	6.1	12.6	4.7
IL-26	0.21	95.35	70.9	4.3	179.1	0.49	2.3	0.42	6.7	14.6	4.6
IL-14	0.17	96.40	71.8	3.0	159.3	0.55	3.4	0.15	6.9	14.8	4.5
IL-87	0.08	102.77	76.6	1.0	151.5	0.51	4.2	0.24	4.1	15.2	4.9
Mean	**0.69**	**57.02**	**67.8**	**3.3**	**162.1**	**0.50**	**3.6**	**0.51**	**6.1**	**15.5**	**4.3**
LSD (0.05)	**0.65**	**40.56**	**4.5**	**5.9**	**29.4**	**0.13**	**10.2**	**0.31**	**1.4**	**2.0**	**0.6**
SE	**0.33**	**20.46**	**2.3**	**3.0**	**14.9**	**0.07**	**5.1**	**0.16**	**0.7**	**1.0**	**0.3**
P	***	**	***	*	ns	ns	**	ns	***	***	***
Minimum	**0.08**	**14.39**	**59.30**	**-0.90**	**138.86**	**0.40**	**-2.80**	**0.15**	**3.45**	**12.25**	**3.31**
Maximum	**1.80**	**102.77**	**79.90**	**11.05**	**188.43**	**0.63**	**19.75**	**0.83**	**7.85**	**17.06**	**4.94**

(2-4.b) Save Valley - moderate heat-drought stress environmental condition

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-92	3.48	2.48	73.7	0.9	132.2	0.45	-	0.75	-	14.6	2.0
IL-107	2.58	5.51	69.2	0.3	130.3	0.45	-	0.80	-	13.8	3.0
IL-108	2.39	10.45	67.0	1.1	133.9	0.45	-	1.10	-	13.1	2.8
IL-102	2.38	15.31	74.2	0.2	137.9	0.50	-	1.00	-	14.5	3.7
IL-62	1.94	20.10	67.0	1.7	122.5	0.50	-	0.65	-	15.0	3.7
IL-17	1.94	23.20	71.6	1.5	131.1	0.50	-	0.65	-	11.3	2.9
IL-16	2.18	23.91	70.3	1.7	155.6	0.45	-	0.80	-	13.3	2.5
IL-13	1.72	23.97	71.0	4.3	131.3	0.40	-	0.95	-	12.4	3.5
IL-31	1.74	24.50	72.5	2.2	124.9	0.50	-	0.60	-	13.3	3.1
IL-34	1.65	25.46	68.0	3.1	120.2	0.40	-	0.70	-	14.8	3.1
IL-69	1.75	25.91	73.4	2.8	136.5	0.45	-	0.70	-	14.4	3.2
IL-53	1.86	26.33	70.7	0.7	115.0	0.50	-	0.75	-	11.9	2.9
IL-47	1.76	27.37	68.1	1.3	127.7	0.50	-	0.80	-	13.0	3.8
IL-100	1.94	28.02	74.8	3.0	141.1	0.50	-	0.95	-	14.7	3.3
IL-63	1.67	28.58	69.4	2.1	112.9	0.45	-	0.80	-	15.3	3.7
IL-101	2.12	28.65	72.2	0.5	116.8	0.45	-	0.95	-	14.8	3.2
IL-60	1.78	29.09	71.4	3.2	124.2	0.45	-	0.85	-	13.0	3.9
IL-42	1.56	29.32	68.6	0.4	143.2	0.45	-	0.95	-	12.7	3.7
IL-98	1.59	31.19	69.5	1.7	119.5	0.50	-	0.70	-	13.8	3.4
IL-33	1.98	31.93	67.7	2.0	117.9	0.50	-	0.75	-	14.5	3.1
IL-7	1.59	32.06	68.0	0.6	108.4	0.50	-	0.80	-	13.0	3.5
IL-43	1.88	32.07	68.7	3.6	141.3	0.40	-	0.80	-	13.3	2.7
IL-23	1.54	34.17	68.7	1.7	119.9	0.45	-	0.75	-	14.5	4.0
IL-75	1.55	34.39	63.9	1.4	126.2	0.45	-	0.65	-	14.6	3.4
IL-76	1.84	35.67	70.7	2.2	121.8	0.45	-	0.75	-	12.9	3.0
IL-40	1.42	37.12	66.2	3.5	114.0	0.50	-	0.80	-	13.2	3.6
IL-99	1.62	37.64	66.7	0.4	124.8	0.45	-	0.65	-	14.5	4.2
IL-82	1.44	38.77	66.8	1.7	134.2	0.45	-	0.75	-	13.0	3.5
IL-103	1.60	38.95	71.8	2.6	136.0	0.50	-	0.80	-	10.6	2.5
IL-48	1.67	38.96	73.3	0.1	133.9	0.45	-	0.75	-	12.9	3.5
IL-5	1.51	40.06	67.5	1.7	122.0	0.45	-	0.95	-	13.2	3.6
IL-25	1.49	40.24	70.2	0.4	127.7	0.50	-	0.70	-	13.9	3.8
IL-77	1.49	40.58	68.1	3.1	118.0	0.45	-	0.70	-	13.7	3.7
IL-71	1.55	40.82	67.8	0.5	137.4	0.50	-	0.70	-	13.7	3.0
IL-96	1.58	40.84	73.4	1.7	129.0	0.45	-	0.50	-	12.6	2.4
IL-1	1.50	41.62	70.4	0.7	127.9	0.45	-	0.75	-	12.9	3.8
IL-15	1.45	43.73	68.4	4.2	117.3	0.40	-	0.70	-	12.8	3.7
IL-51	1.36	45.45	67.7	-0.4	132.6	0.40	-	0.70	-	13.9	3.7

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-20	1.55	46.75	68.0	1.3	117.0	0.45	-	0.70	-	11.3	3.1
IL-59	1.22	47.98	71.7	0.8	107.8	0.45	-	0.60	-	13.7	4.2
IL-21	1.27	48.02	69.3	1.4	120.2	0.45	-	0.70	-	14.1	3.9
IL-44	1.39	48.36	68.4	3.2	124.4	0.45	-	0.50	-	15.6	3.3
IL-80	1.34	48.72	72.5	4.2	147.1	0.45	-	0.75	-	12.8	3.8
IL-4	1.22	48.76	66.9	1.9	102.4	0.45	-	0.55	-	15.3	3.8
IL-57	1.27	50.23	73.0	0.9	120.5	0.40	-	0.75	-	14.2	3.8
IL-93	1.26	50.30	75.8	0.3	101.7	0.45	-	0.75	-	10.3	3.9
IL-2	1.45	50.40	68.6	1.9	129.9	0.45	-	0.60	-	11.7	3.6
IL-38	1.38	51.50	70.7	3.4	113.6	0.50	-	0.90	-	13.6	3.6
IL-29	1.26	51.69	66.8	0.5	108.7	0.50	-	0.50	-	14.3	3.6
IL-97	1.21	52.78	71.9	3.7	121.3	0.50	-	0.75	-	12.6	3.2
IL-104	1.26	52.89	74.7	0.3	96.1	0.45	-	0.90	-	12.9	4.1
IL-68	1.22	53.03	69.3	1.8	104.1	0.50	-	0.75	-	12.1	4.1
IL-81	1.26	53.21	73.6	0.1	142.0	0.40	-	0.65	-	13.3	4.0
IL-73	1.32	53.40	68.5	1.1	111.6	0.45	-	0.80	-	12.9	3.3
IL-86	1.43	53.65	75.3	5.6	134.2	0.45	-	0.70	-	10.4	3.6
IL-36	1.13	54.12	69.2	1.8	119.4	0.50	-	0.70	-	13.2	4.2
IL-41	1.19	54.38	68.0	3.8	123.3	0.45	-	0.35	-	14.6	3.6
IL-49	1.19	56.12	63.2	3.5	112.6	0.45	-	0.60	-	14.0	4.0
IL-46	1.11	56.29	69.1	0.7	110.1	0.45	-	0.70	-	14.5	3.9
IL-64	1.19	56.56	69.0	2.2	132.1	0.40	-	0.65	-	13.9	4.3
IL-11	1.20	56.92	69.1	1.9	138.8	0.40	-	0.70	-	13.5	3.8
IL-22	1.15	57.71	68.8	1.0	115.0	0.45	-	0.50	-	13.7	3.7
IL-9	1.10	58.62	69.3	1.3	116.5	0.50	-	0.60	-	11.9	3.5
IL-35	1.22	59.48	70.4	2.1	123.7	0.40	-	0.90	-	10.7	3.6
IL-56	1.13	59.85	72.5	1.2	139.1	0.45	-	0.70	-	11.4	3.3
IL-55	1.11	61.32	68.4	4.1	121.2	0.50	-	0.55	-	14.6	3.9
IL-74	1.10	62.47	69.3	2.4	113.6	0.50	-	0.75	-	11.6	3.6
IL-6	1.00	63.49	69.0	1.9	124.6	0.45	-	0.45	-	13.5	3.4
IL-66	0.91	65.23	70.2	2.2	137.5	0.45	-	0.50	-	14.0	3.3
IL-88	1.10	65.84	75.2	5.9	136.8	0.40	-	0.55	-	10.1	3.5
IL-8	0.98	65.92	68.4	1.2	115.0	0.45	-	0.60	-	12.8	4.2
IL-85	1.02	66.33	78.0	0.3	128.5	0.50	-	0.70	-	8.7	3.6
IL-10	0.99	66.39	66.1	3.8	106.6	0.45	-	0.50	-	12.2	3.5
IL-70	1.07	67.21	68.0	1.8	97.4	0.45	-	0.70	-	14.1	3.8
IL-94	0.90	67.70	78.0	3.7	89.4	0.45	-	0.65	-	10.5	4.5
IL-67	0.93	68.55	70.6	1.4	125.3	0.40	-	0.65	-	11.9	4.0
IL-52	0.83	68.94	71.3	3.7	116.6	0.45	-	0.65	-	10.0	4.4
IL-3	0.98	69.02	69.3	-0.1	115.3	0.50	-	0.55	-	13.8	3.5
IL-90	1.02	69.95	74.3	0.1	103.0	0.50	-	0.65	-	11.1	3.5
IL-54	1.04	71.20	67.3	2.0	119.6	0.45	-	0.40	-	8.7	3.6

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-72	0.96	71.32	67.8	4.0	121.5	0.40	-	0.45	-	14.6	3.6
IL-24	0.92	71.49	73.2	0.8	122.1	0.45	-	0.55	-	14.2	3.7
IL-18	0.87	72.01	65.8	1.8	104.2	0.50	-	0.60	-	13.3	4.5
IL-89	0.84	72.08	74.5	0.7	136.3	0.40	-	0.60	-	12.2	4.1
IL-12	0.86	72.83	72.4	5.3	112.7	0.45	-	0.60	-	12.9	3.8
IL-91	0.87	73.51	76.6	0.0	94.1	0.45	-	0.75	-	12.5	4.3
IL-84	0.81	74.47	74.4	2.3	116.6	0.50	-	0.55	-	9.3	2.9
IL-78	0.78	75.79	68.6	2.5	106.1	0.50	-	0.65	-	11.2	4.0
IL-106	0.76	76.47	69.9	3.4	119.6	0.50	-	0.70	-	13.4	4.2
IL-83	0.72	77.90	79.6	1.4	121.7	0.50	-	0.85	-	7.8	3.8
IL-26	0.78	78.13	75.2	3.2	139.4	0.40	-	0.50	-	9.9	3.8
IL-39	0.87	79.07	74.2	4.1	122.0	0.40	-	0.35	-	10.8	3.9
IL-50	0.80	79.08	71.0	1.0	141.7	0.45	-	0.60	-	12.6	4.1
IL-32	0.81	79.62	67.5	2.3	115.9	0.45	-	0.55	-	13.2	3.9
IL-58	0.81	79.81	67.9	1.2	125.2	0.45	-	0.45	-	13.4	3.7
IL-61	0.74	80.18	67.8	2.0	126.7	0.45	-	0.55	-	13.0	3.6
IL-30	0.75	80.40	75.7	0.4	140.1	0.50	-	0.65	-	10.0	4.1
IL-105	0.67	81.91	74.2	0.0	105.9	0.45	-	0.45	-	13.8	3.9
IL-79	0.84	84.77	72.2	1.9	127.8	0.45	-	0.55	-	12.8	3.8
IL-95	0.64	84.88	74.4	0.4	115.9	0.45	-	0.60	-	13.0	4.8
IL-14	0.75	85.63	68.8	1.1	115.1	0.40	-	0.35	-	13.7	3.8
IL-27	0.54	86.32	67.8	4.3	115.2	0.40	-	0.40	-	14.6	4.2
IL-45	0.73	86.39	72.4	4.6	142.4	0.45	-	0.60	-	10.4	3.9
IL-37	0.50	88.61	67.5	1.7	107.3	0.45	-	0.45	-	14.4	5.0
IL-28	0.67	89.02	71.5	2.7	108.2	0.50	-	0.70	-	11.5	4.3
IL-65	0.56	89.41	67.9	4.6	125.1	0.45	-	0.30	-	14.2	4.2
IL-19	0.66	92.79	70.6	2.5	109.7	0.40	-	0.55	-	8.3	4.6
IL-87	0.57	93.27	76.7	1.1	119.5	0.40	-	0.70	-	11.2	4.5
Mean	**1.28**	**54.10**	**70.1**	**1.9**	**122.1**	**0.46**	**-**	**0.67**	**-**	**12.8**	**3.7**
LSD (0.05)	**0.81**	**37.53**	**4.0**	**3.4**	**28.3**	**0.11**	**-**	**0.34**	**-**	**3.7**	**1.1**
SE	**0.41**	**18.93**	**2.0**	**1.7**	**14.3**	**0.05**	**-**	**0.17**	**-**	**1.9**	**0.5**
p	***	***	***	*	*	ns	-	***	-	*	**
Min	**0.50**	**2.48**	**63.15**	**-0.35**	**89.42**	**0.40**	**-**	**0.30**	**-**	**7.82**	**1.99**
Max	**3.48**	**93.27**	**79.60**	**5.90**	**155.62**	**0.50**	**-**	**1.10**	**-**	**15.63**	**5.02**

(2-4.c) Chókwè - random drought stress environmental condition

Inbred line	Grain Yield		Anth	ASI	Plant	Ear	Stem	Ears/	Leaf	Num	Ear
code	GW	Rank	Date		Height	Pos.	Lodg.	Plant	Sen.	Plants	Aspect
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-92	2.31	-7.37	63.3	5.2	-	-	8.3	1.39	1.0	12.8	1.9
IL-102	2.01	0.86	65.1	4.4	-	-	27.4	1.68	1.0	14.6	3.0
IL-53	1.91	3.22	63.9	4.5	-	-	36.5	1.16	1.0	14.8	2.6
IL-101	1.83	4.84	65.2	6.1	-	-	10.4	1.66	1.0	15.6	2.3
IL-16	1.85	8.64	65.2	10.6	-	-	18.0	1.05	1.0	15.7	2.1
IL-90	1.77	8.85	65.5	4.7	-	-	28.0	1.29	1.0	15.0	4.0
IL-33	1.76	9.72	62.2	4.5	-	-	20.4	1.26	0.9	15.4	3.0
IL-76	1.75	10.29	63.1	5.6	-	-	10.4	1.45	0.9	12.9	3.0
IL-1	1.72	11.09	63.4	8.5	-	-	10.2	1.39	1.0	12.8	3.2
IL-44	1.73	11.13	64.6	4.3	-	-	45.7	1.12	1.0	16.5	2.7
IL-81	1.73	11.28	71.6	4.5	-	-	6.4	1.15	1.0	14.9	3.7
IL-96	1.93	11.30	69.9	6.0	-	-	18.3	1.27	0.9	13.1	2.5
IL-100	1.70	13.44	64.9	5.1	-	-	5.5	1.57	1.0	15.5	3.1
IL-10	1.68	13.91	64.6	8.1	-	-	43.2	1.11	0.9	17.4	2.8
IL-71	1.75	14.30	62.0	7.0	-	-	19.8	0.95	0.9	16.8	3.0
IL-34	1.67	14.81	64.3	4.0	-	-	35.4	0.85	1.0	14.1	1.9
IL-103	1.76	15.66	64.6	7.0	-	-	13.0	1.39	1.0	14.9	3.2
IL-17	1.67	16.10	65.1	8.9	-	-	25.5	0.96	1.0	15.2	2.9
IL-43	1.66	16.59	66.2	4.6	-	-	6.7	1.08	0.9	14.4	3.1
IL-4	1.70	19.07	65.6	5.7	-	-	50.8	0.82	1.0	15.0	3.0
IL-13	1.63	19.73	66.1	9.1	-	-	9.1	1.12	1.0	15.1	3.2
IL-64	1.71	20.55	65.2	3.1	-	-	4.7	1.45	1.0	14.6	3.3
IL-69	1.63	20.99	66.1	4.4	-	-	32.3	1.32	1.0	16.0	3.4
IL-77	1.57	21.64	60.8	5.6	-	-	48.2	1.16	1.0	14.1	3.7
IL-107	1.70	21.73	64.3	5.6	-	-	21.9	1.27	1.0	13.6	3.2
IL-72	1.57	23.14	62.5	6.1	-	-	11.5	0.94	1.0	15.1	3.2
IL-9	1.58	23.80	66.8	5.9	-	-	79.9	1.23	1.0	14.8	2.7
IL-68	1.61	23.91	64.8	3.6	-	-	61.0	0.97	1.0	15.5	2.7
IL-105	1.56	24.07	65.0	6.5	-	-	45.6	1.01	1.0	18.8	2.5
IL-98	1.59	24.43	65.2	4.3	-	-	30.2	1.30	1.0	13.6	3.3
IL-47	1.53	25.33	63.6	7.1	-	-	44.6	1.14	1.0	15.8	3.2
IL-35	1.61	25.75	64.8	4.4	-	-	38.2	1.13	1.0	14.9	3.4
IL-99	1.51	26.57	64.6	4.5	-	-	18.3	1.08	0.9	16.0	2.0
IL-36	1.61	27.36	62.6	5.8	-	-	4.5	1.23	1.0	14.5	3.7
IL-8	1.56	27.83	64.0	8.5	-	-	37.5	1.23	0.9	13.4	3.6
IL-75	1.53	28.28	60.6	5.4	-	-	16.2	1.15	1.0	12.7	2.8
IL-62	1.50	29.04	64.0	5.4	-	-	40.7	1.27	1.0	15.1	3.5
IL-7	1.54	29.49	63.6	7.0	-	-	25.3	1.26	0.9	14.5	3.3
IL-20	1.59	30.63	66.1	7.5	-	-	43.4	1.03	1.0	12.4	2.7

Inbred line	Grain Yield		Anth	ASI	Plant	Ear	Stem	Ears/	Leaf	Num	Ear
code	GW	Rank	Date		Height	Pos.	Lodg.	Plant	Sen.	Plants	Aspect
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-93	1.46	31.98	72.5	4.5	-	-	32.3	1.29	0.9	14.0	4.1
IL-49	1.47	33.37	64.8	6.5	-	-	43.9	1.15	0.9	14.6	3.7
IL-55	1.43	33.50	62.8	4.9	-	-	50.2	0.99	0.9	16.7	3.2
IL-80	1.43	34.55	66.1	5.6	-	-	6.9	1.17	0.9	15.6	3.9
IL-31	1.44	35.35	64.3	6.0	-	-	31.2	1.08	1.0	15.2	2.9
IL-22	1.43	35.57	63.2	4.7	-	-	34.0	0.95	1.0	17.1	3.0
IL-46	1.40	35.63	64.0	9.2	-	-	19.4	1.36	1.0	15.8	3.4
IL-97	1.40	40.32	70.9	6.5	-	-	32.9	0.91	1.0	14.7	3.0
IL-11	1.37	41.80	62.9	5.9	-	-	38.9	1.00	1.0	15.4	3.8
IL-23	1.32	42.35	63.6	9.0	-	-	6.0	1.13	1.0	13.4	2.7
IL-57	1.31	42.57	64.7	7.4	-	-	11.0	1.64	1.0	13.8	4.2
IL-60	1.32	43.31	72.7	5.6	-	-	16.2	1.08	1.0	14.9	4.0
IL-5	1.36	44.02	65.9	7.0	-	-	45.4	1.17	1.0	13.8	3.0
IL-40	1.33	44.82	64.4	6.5	-	-	36.8	0.94	1.0	17.1	3.4
IL-48	1.30	44.84	64.8	8.5	-	-	17.7	1.27	1.0	13.4	3.5
IL-73	1.35	45.11	64.3	8.8	-	-	31.9	1.15	1.0	15.4	3.3
IL-59	1.32	46.75	65.8	6.6	-	-	27.2	1.15	1.0	15.0	3.8
IL-54	1.29	47.22	63.3	5.6	-	-	22.3	1.27	1.0	14.4	2.9
IL-63	1.29	47.23	70.6	6.6	-	-	15.0	0.99	1.0	14.0	4.2
IL-15	1.21	50.48	63.3	8.6	-	-	19.2	1.04	1.0	14.4	3.6
IL-89	1.24	50.85	70.2	6.9	-	-	49.5	1.32	0.9	13.9	3.1
IL-74	1.24	50.89	65.0	8.6	-	-	63.5	1.22	1.0	12.0	3.1
IL-86	1.26	51.06	71.4	5.7	-	-	19.7	0.94	1.0	13.7	2.7
IL-84	1.19	53.14	72.8	8.6	-	-	31.5	1.34	1.0	14.9	3.0
IL-24	1.24	53.26	67.7	7.4	-	-	55.1	1.13	0.9	13.4	3.4
IL-108	1.19	55.13	73.3	6.0	-	-	46.5	1.02	1.0	15.0	3.8
IL-66	1.17	55.88	64.6	8.6	-	-	21.8	1.31	0.9	15.2	3.3
IL-78	1.18	55.95	61.6	9.6	-	-	58.5	0.98	1.0	14.5	3.9
IL-42	1.17	56.32	64.9	8.1	-	-	13.5	1.15	1.0	15.3	3.6
IL-27	1.21	57.40	66.2	7.4	-	-	32.2	1.01	0.9	13.9	3.6
IL-38	1.19	58.25	64.8	8.5	-	-	6.3	1.08	1.0	15.2	3.6
IL-2	1.17	58.31	64.2	9.1	-	-	28.6	1.15	1.0	15.0	3.0
IL-29	1.13	58.36	65.7	3.5	-	-	66.3	1.02	1.0	16.5	3.6
IL-82	1.11	62.68	65.1	6.5	-	-	21.8	1.28	1.0	14.5	3.9
IL-51	1.08	62.98	61.7	8.0	-	-	72.0	1.43	1.0	12.8	3.4
IL-58	1.13	63.03	64.2	8.3	-	-	45.5	1.13	1.0	15.3	3.5
IL-106	1.08	63.27	65.1	8.2	-	-	19.2	1.20	1.0	15.1	3.3
IL-18	1.07	65.21	65.3	8.6	-	-	49.0	1.49	1.0	16.6	3.9
IL-104	1.06	67.31	71.8	7.9	-	-	63.2	1.04	1.0	16.9	3.1
IL-41	1.07	68.34	60.9	9.0	-	-	40.6	0.89	1.0	15.0	3.2
IL-25	1.07	68.50	64.2	9.9	-	-	15.5	1.26	1.0	14.5	3.5
IL-30	1.02	68.63	66.1	7.9	-	-	47.9	1.23	1.0	15.5	3.8

Inbred line	Grain Yield		Anth	ASI	Plant	Ear	Stem	Ears/	Leaf	Num	Ear
code	GW	Rank	Date		Height	Pos.	Lodg.	Plant	Sen.	Plants	Aspect
	t/ha	Rank	d	d	cm	0-1	%	#	1-10	#	1-5
IL-14	1.04	71.00	72.1	7.4	-	-	33.1	0.97	1.0	13.9	3.2
IL-39	1.03	71.09	71.4	8.0	-	-	19.2	0.86	1.0	16.9	3.3
IL-70	0.99	73.53	66.2	8.0	-	-	31.8	1.13	0.9	14.3	3.9
IL-52	0.96	73.92	64.9	8.5	-	-	26.5	1.11	1.0	12.4	3.4
IL-50	0.98	76.16	69.7	9.5	-	-	51.2	1.09	0.9	14.7	3.7
IL-6	0.98	77.34	64.7	8.5	-	-	37.8	1.10	1.0	13.2	3.8
IL-56	0.95	77.60	66.5	7.5	-	-	47.2	0.98	1.0	13.2	3.0
IL-28	0.94	79.13	70.7	5.0	-	-	11.8	0.88	1.0	12.4	3.4
IL-65	0.92	79.29	65.0	8.8	-	-	43.8	0.80	0.9	14.9	3.8
IL-87	0.94	79.62	72.6	9.0	-	-	22.9	1.31	1.0	15.3	3.9
IL-79	0.93	79.79	72.3	8.5	-	-	14.2	0.97	1.0	14.8	3.4
IL-94	0.87	84.70	71.4	9.1	-	-	11.9	0.87	1.0	19.1	4.0
IL-67	0.74	85.10	71.4	8.9	-	-	19.7	0.95	1.0	16.0	3.6
IL-91	0.81	85.15	69.9	10.0	-	-	87.1	0.78	1.0	19.4	3.9
IL-3	0.84	85.32	66.5	7.6	-	-	56.2	1.03	0.9	13.7	4.1
IL-45	0.81	86.17	65.9	8.3	-	-	74.3	0.85	0.9	14.1	3.5
IL-85	0.80	87.16	72.7	8.4	-	-	4.8	1.10	1.0	9.6	3.0
IL-21	0.79	87.80	65.4	8.3	-	-	23.8	0.92	1.0	14.0	4.0
IL-88	0.79	88.32	72.1	8.6	-	-	11.9	1.07	0.5	13.9	4.0
IL-12	0.75	89.16	68.6	6.0	-	-	47.7	1.16	0.9	13.9	3.7
IL-19	0.73	90.31	66.6	7.5	-	-	40.9	1.01	1.0	13.7	3.0
IL-26	0.71	90.88	71.9	8.4	-	-	18.9	0.91	0.9	13.1	3.4
IL-61	0.62	95.07	65.3	7.6	-	-	29.4	1.12	1.0	15.6	3.9
IL-37	0.62	96.70	62.1	8.5	-	-	38.0	0.86	1.0	13.8	4.2
IL-83	0.46	100.32	73.6	9.0	-	-	30.4	0.72	0.9	18.1	4.6
IL-95	0.26	102.43	72.7		-	-	4.1	0.63	1.0	12.0	4.8
IL-32	0.50	102.74	64.6	9.4	-	-	2.7	0.72	1.0	15.0	3.7
Mean	**1.30**	**47.25**	**66.2**	**7.0**			**30.6**	**1.12**	**1.0**	**14.7**	**3.3**
LSD (0.05)	**0.52**	**38.02**	**1.9**	**1.6**			**32.0**	**0.36**	**0.1**	**3.4**	**0.9**
MSe	**0.07**	**360.37**	**0.9**	**0.7**			**273.4**	**0.03**	**0.0**	**3.1**	**0.2**
CV	**19.85**	**40.17**	**1.4**	**11.5**			**54.1**	**16.49**	**6.7**	**11.9**	**14.1**
p	**0.000**	**0.000**	**0.000**	**0.000**			**0.000**	**0.000**	**0.038**	**0.022**	**0.000**
Min	**0.26**	**-7.37**	**60.6**	**3.1**			**2.7**	**0.63**	**0.5**	**9.6**	**1.9**
Max	**2.31**	**102.74**	**73.6**	**10.6**			**87.1**	**1.68**	**1.0**	**19.4**	**4.8**

(2-4.d) Chókwè - unstressed environmental condition

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem Lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	t/ha	d	d	cm	0-1	%	#	1-10	#	1-5
IL-53	6.09	-6.32	48.9	1.9	211.4	0.55	-	1.19	0.8	19.5	2.3
IL-107	4.53	1.93	55.3	2.9	182.4	0.52	-	1.54	1.0	16.7	3.1
IL-92	5.98	2.80	60.2	3.5	216.7	0.59	-	1.14	0.5	19.0	2.8
IL-101	4.97	3.57	57.0	-2.0	199.2	0.55	-	1.43	0.8	18.4	3.1
IL-47	5.12	4.23	54.4	3.3	214.4	0.57	-	1.47	0.9	15.4	2.6
IL-10	4.63	4.60	54.7	2.6	187.5	0.61	-	1.38	0.9	16.0	2.8
IL-102	4.70	5.76	54.4	2.3	203.8	0.51	-	1.53	0.9	16.3	3.2
IL-54	4.48	6.47	51.7	3.2	215.0	0.50	-	1.13	1.0	19.2	3.3
IL-20	4.29	7.37	55.6	2.6	174.3	0.50	-	1.30	0.5	14.4	2.7
IL-38	4.53	8.83	54.4	3.0	200.6	0.56	-	1.34	0.8	17.2	3.4
IL-71	4.12	14.50	58.6	-0.9	238.1	0.53	-	1.27	1.0	14.9	3.6
IL-46	4.23	15.40	55.7	1.5	204.9	0.54	-	1.43	0.9	16.2	3.7
IL-33	4.17	15.98	53.8	3.1	186.7	0.58	-	1.17	0.9	14.8	2.6
IL-27	4.25	16.16	55.3	3.1	204.6	0.51	-	1.13	0.8	15.1	3.7
IL-75	3.94	16.44	52.8	1.1	199.3	0.55	-	1.20	1.0	15.0	2.9
IL-17	4.14	18.61	55.8	0.4	186.4	0.66	-	1.16	0.9	13.9	2.4
IL-73	4.02	21.22	54.7	3.0	194.3	0.58	-	1.33	0.9	15.3	3.4
IL-4	3.90	22.91	56.5	-0.4	190.7	0.63	-	1.17	1.0	14.3	3.3
IL-9	3.99	23.23	48.4	2.6	196.5	0.60	-	1.11	0.8	14.7	3.0
IL-100	4.01	23.26	55.8	2.7	195.6	0.57	-	1.76	0.9	15.6	4.0
IL-31	4.57	23.58	56.2	2.6	180.8	0.57	-	1.08	0.4	18.2	2.3
IL-1	3.97	24.32	52.4	2.5	231.6	0.52	-	1.28	0.9	17.0	3.3
IL-108	4.20	25.30	56.8	0.1	180.3	0.50	-	1.33	1.0	15.6	4.5
IL-55	3.69	25.80	55.1	3.0	192.1	0.57	-	1.13	1.0	17.6	3.8
IL-76	4.01	26.52	52.6	3.4	206.7	0.53	-	0.93	0.7	18.2	2.9
IL-97	3.63	27.90	56.4	2.4	211.8	0.60	-	1.16	0.8	16.0	3.8
IL-23	3.85	28.15	54.9	2.6	193.2	0.50	-	1.36	0.9	16.1	5.0
IL-22	3.75	28.30	53.9	1.9	193.6	0.43	-	1.34	1.0	15.5	3.6
IL-77	3.72	30.74	48.8	1.7	219.9	0.57	-	1.48	0.9	13.2	4.1
IL-105	3.79	32.24	58.9	2.5	192.6	0.48	-	1.01	0.9	19.8	2.7
IL-7	3.55	32.70	54.1	3.0	180.8	0.52	-	1.20	1.0	14.4	3.7
IL-29	3.62	32.97	53.6	2.2	207.5	0.58	-	1.26	1.0	20.3	3.5
IL-51	3.58	33.99	52.9	2.6	175.8	0.62	-	1.07	1.0	19.1	5.0
IL-103	3.51	34.75	58.0	4.4	221.7	0.55	-	1.49	0.8	14.0	3.5
IL-43	3.61	35.58	55.8	2.5	205.1	0.55	-	1.23	0.9	15.5	3.7
IL-44	3.37	39.37	55.9	0.9	191.6	0.68	-	1.01	0.8	18.6	2.4
IL-78	3.55	39.72	54.4	2.5	180.6	0.54	-	1.22	1.0	18.6	3.2
IL-40	3.28	40.36	51.9	2.9	168.6	0.58	-	1.18	0.6	13.2	3.9
IL-82	3.21	41.31	54.6	1.5	190.6	0.56	-	1.40	0.8	13.4	3.1

Inbred line	Grain Yield		Anth	ASI	Plant	Ear	Stem	Ears/	Leaf	Num	Ear
code	GW	Rank	Date		Height	Pos.	Lodg.	Plant	Sen.	Plants	Aspect
	t/ha	t/ha	d	d	cm	0-1	%	#	1-10	#	1-5
IL-2	3.33	41.31	52.7	5.1	198.4	0.54	-	1.08	0.9	16.3	3.1
IL-89	3.35	42.67	58.7	1.0	171.2	0.59	-	1.22	0.7	15.1	3.7
IL-62	3.23	44.73	54.4	2.5	226.3	0.54	-	1.24	0.8	15.2	3.4
IL-24	3.21	45.00	57.2	3.0	174.1	0.54	-	1.17	0.8	15.6	3.0
IL-98	3.28	46.50	55.3	1.7	201.4	0.59	-	1.06	1.0	15.7	2.6
IL-72	3.13	47.64	53.4	4.6	179.6	0.58	-	1.10	0.9	15.5	3.3
IL-90	3.09	48.21	56.5	2.1	157.9	0.57	-	1.33	0.9	13.7	2.6
IL-80	3.16	50.39	56.9	4.6	209.6	0.59	-	1.38	0.6	15.5	4.2
IL-87	3.04	50.53	62.5	2.4	167.1	0.53	-	1.75	0.2	14.8	3.6
IL-49	2.98	52.74	55.4	1.0	166.8	0.59	-	1.11	1.0	17.1	4.2
IL-88	3.05	52.93	61.7	2.4	224.7	0.46	-	0.99	0.9	13.7	3.4
IL-34	2.99	52.98	55.0	3.0	197.9	0.55	-	1.00	0.9	13.3	2.4
IL-69	2.99	53.16	58.8	0.5	212.5	0.55	-	1.47	0.8	15.0	3.1
IL-59	3.02	54.71	56.0	1.9	183.7	0.62	-	1.11	0.5	15.0	3.9
IL-36	2.94	55.08	54.0	2.6	189.2	0.56	-	1.11	0.8	16.1	3.9
IL-94	2.93	55.47	62.2	1.9	178.7	0.50	-	1.07	0.5	21.1	4.7
IL-99	2.79	56.48	52.4	4.1	189.5	0.57	-	1.01	0.9	14.4	3.5
IL-5	2.86	56.60	53.3	3.1	185.4	0.63	-	1.16	1.0	14.3	3.7
IL-64	2.93	57.86	53.8	2.0	224.9	0.62	-	1.15	1.0	21.8	4.0
IL-68	2.83	58.04	56.1	1.3	185.6	0.53	-	0.92	0.9	15.8	3.2
IL-52	2.94	58.68	55.8	1.8	194.6	0.55	-	1.24	1.0	13.4	3.6
IL-79	2.85	58.89	55.0	0.9	188.1	0.54	-	1.25	0.8	16.5	4.0
IL-11	2.78	61.35	55.0	2.0	183.8	0.65	-	1.19	1.0	17.9	3.9
IL-21	2.72	62.65	54.3	2.7	211.7	0.57	-	1.06	1.0	17.7	4.9
IL-91	2.61	64.35	63.9	-0.9	182.1	0.59	-	0.97	1.0	15.5	3.6
IL-13	2.48	64.45	56.7	3.6	203.8	0.51	-	1.19	0.8	16.3	4.0
IL-35	2.69	65.57	55.0	2.4	180.9	0.60	-	1.12	0.8	13.3	3.7
IL-14	2.63	65.61	60.4	1.5	165.1	0.57	-	0.94	1.0	15.0	3.5
IL-45	2.69	66.02	55.4	2.4	195.6	0.63	-	1.00	1.0	15.2	3.8
IL-106	2.85	66.32	55.3	3.5	208.5	0.60	-	1.67	1.0	14.8	4.0
IL-8	2.56	66.43	54.0	2.5	187.2	0.54	-	1.12	1.0	14.9	4.8
IL-48	2.73	68.82	56.9	0.3	209.0	0.63	-	0.91	1.0	13.4	3.6
IL-15	2.59	69.01	57.5	2.0	179.0	0.55	-	0.98	1.0	13.9	3.4
IL-18	2.57	69.13	56.3	0.5	191.7	0.53	-	1.64	1.0	15.3	4.7
IL-74	2.52	70.71	54.8	3.7	193.0	0.60	-	1.04	1.0	15.2	3.9
IL-86	2.52	71.51	56.8	-2.0	211.4	0.54	-	0.99	0.5	13.6	4.6
IL-6	2.51	71.58	54.5	2.0	181.8	0.48	-	0.86	1.0	18.8	3.8
IL-104	2.53	71.72	62.0	2.0	189.4	0.50	-	1.14	0.8	18.3	3.7
IL-66	2.42	72.82	55.6	3.1	190.3	0.57	-	1.21	0.9	15.4	3.1
IL-93	2.54	73.79	61.8	2.1	176.0	0.52	-	1.27	0.5	14.4	4.1
IL-50	2.37	74.06	56.9	-0.1	185.9	0.54	-	1.21	1.0	15.7	3.4
IL-42	2.43	75.33	53.5	2.5	185.6	0.60	-	1.18	1.0	15.3	3.8

Inbred line code	Grain Yield		Anth Date	ASI	Plant Height	Ear Pos.	Stem Lodg.	Ears/ Plant	Leaf Sen.	Num Plants	Ear Aspect
	GW	Rank									
	t/ha	t/ha	d	d	cm	0-1	%	#	1-10	#	1-5
IL-60	2.31	76.87	61.0	3.4	174.1	0.71	-	1.01	0.6	16.9	4.5
IL-19	2.39	77.89	58.8	1.6	190.1	0.51	-	1.07	1.0	14.3	4.6
IL-30	2.44	78.17	56.8	2.6	194.0	0.53	-	0.96	1.0	16.1	3.4
IL-57	2.56	78.42	57.7	1.9	202.3	0.51	-	1.51	0.6	16.0	4.3
IL-3	2.31	78.85	54.9	3.0	214.4	0.62	-	1.37	1.0	14.2	2.8
IL-70	2.19	81.63	55.6	3.4	180.6	0.53	-	0.93	0.9	14.8	3.7
IL-63	2.12	82.06	61.5	2.8	149.3	0.54	-	1.06	0.5	14.8	4.9
IL-81	2.08	83.88	62.0	2.5	209.5	0.55	-	1.18	0.8	13.8	4.5
IL-65	2.03	84.37	55.2	2.0	214.1	0.50	-	0.95	0.8	16.6	3.7
IL-37	2.28	84.53	50.5	2.0	187.2	0.53	-	1.27	1.0	15.0	3.8
IL-96	2.12	86.01	57.1	-0.1	170.1	0.57	-	1.05	0.7	15.6	2.5
IL-12	1.72	89.45	57.9	3.5	180.9	0.49	-	1.34	1.0	14.2	4.0
IL-25	1.59	89.58	55.0	4.0	209.6	0.49	-	0.85	1.0	15.5	4.1
IL-28	1.67	90.43	56.8	2.0	198.3	0.49	-	1.05	1.0	12.5	4.2
IL-84	1.44	91.21	62.9	3.0	157.3	0.60	-	1.10	0.1	15.9	4.5
IL-58	2.00	91.58	54.5	2.9	182.8	0.55	-	0.95	0.9	15.5	4.0
IL-41	1.67	93.13	54.4	3.0	184.3	0.54	-	0.96	1.0	15.3	3.7
IL-83	1.47	93.66	63.6	3.4	181.3	0.62	-	0.90	0.3	13.7	4.3
IL-26	1.53	93.86	61.8	2.4	210.8	0.58	-	0.75	0.9	12.7	3.5
IL-85	1.89	94.83	62.0	2.4	203.7	0.60	-	1.00	0.4	15.6	4.1
IL-32	1.86	95.25	56.3	2.0	179.4	0.57	-	0.88	0.8	15.2	3.8
IL-16	1.69	95.74	55.4	3.0	225.1	0.59	-	1.08	0.9	15.6	2.8
IL-39	1.83	98.07	59.9	4.1	188.9	0.55	-	1.24	1.0	14.8	3.7
IL-56	1.56	98.15	58.0	0.5	224.0	0.55	-	1.05	1.0	13.4	3.4
IL-67	1.24	101.79	61.3	3.1	197.9	0.66	-	0.84	0.3	14.9	4.3
IL-95	0.30	106.70	63.0	2.0	140.6	0.60	-	0.37	0.8	15.3	4.5
IL-61	1.29	107.65	55.7	1.9	185.9	0.53	-	1.27	0.9	15.1	3.9
Mean	**3.04**	**53.39**	**56.2**	**2.2**	**193.4**	**0.56**		**1.17**	**0.8**	**15.7**	**3.6**
LSD (0.05)	**1.20**	**33.96**	**2.2**	**1.9**	**32.9**	**0.10**		**0.31**	**0.1**	**4.0**	**1.2**
MSe	**0.40**	**343.73**	**1.3**	**0.9**	**276.0**	**0.00**		**0.02**	**0.0**	**4.0**	**0.4**
CV	**20.78**	**34.73**	**2.0**	**42.1**	**8.6**	**8.80**		**13.52**	**7.1**	**12.8**	**17.4**
p	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		**0.000**	**0.000**	**0.002**	**0.000**
Min	**0.30**	**-6.32**	**48.4**	**-2.0**	**140.6**	**0.43**		**0.37**	**0.1**	**12.5**	**2.3**
Max	**6.09**	**107.65**	**63.9**	**5.1**	**238.1**	**0.71**		**1.76**	**1.0**	**21.8**	**5.0**

(2-4.e) Combined environment

Inbred line	Grain yield rank (GY-Rank) per environment					Geometric mean productivity (GMP)				ASI	Plant height	Ear pos.	Stem lodg.	Ears/ plant	Leaf sen.	Num. plants	Ear Asp.
code	SHDS	MHDS	RDS	OPT	Across	SHDS vs MHDS	SHDS vs OPT	MHDS vs OPT	Average								
	Rank	Rank	Rank	Rank	Rank	#	#	#	#	d	cm	0-1	%	#	1-10	#	1-5
IL-92	27.85	2.48	-7.37	2.80	6.44	2.20	2.88	4.56	3.21	2.7	169.5	0.54	-0.5	0.98	6.2	14.8	2.7
IL-107	17.47	5.51	21.73	1.93	11.66	2.03	2.69	3.41	2.71	2.4	160.3	0.48	4.7	1.02	8.2	14.8	3.2
IL-53	38.84	26.33	3.22	-6.32	15.52	1.41	2.55	3.36	2.44	2.1	160.0	0.56	10.3	0.91	7.2	15.7	2.9
IL-101	25.34	28.65	4.84	3.57	15.60	1.57	2.40	3.24	2.40	1.3	162.5	0.50	0.1	1.22	7.6	16.1	3.1
IL-17	22.85	23.20	16.10	18.61	20.19	1.44	2.11	2.84	2.13	3.5	160.3	0.59	2.3	0.86	7.7	14.2	3.0
IL-102	71.42	15.31	0.86	5.76	23.34	1.14	1.61	3.34	2.03	1.9	171.2	0.51	3.2	1.15	7.9	15.4	3.6
IL-31	14.39	24.50	35.35	23.58	24.46	1.77	2.87	2.82	2.48	4.1	152.4	0.55	1.0	0.85	6.1	15.8	3.0
IL-47	42.84	27.37	25.33	4.23	24.94	1.15	1.97	3.00	2.04	3.3	164.6	0.53	-1.5	0.99	7.5	15.1	3.5
IL-76	29.47	35.67	10.29	26.52	25.49	1.46	2.16	2.72	2.11	3.9	163.1	0.51	11.6	0.95	7.1	14.9	3.3
IL-43	19.69	32.07	16.59	35.58	25.98	1.59	2.21	2.60	2.14	2.8	174.4	0.46	0.5	0.89	8.1	14.9	3.3
IL-33	52.17	31.93	9.72	15.98	27.45	1.15	1.67	2.87	1.90	4.5	155.3	0.54	2.5	0.96	7.6	15.3	3.2
IL-108	21.50	10.45	55.13	25.30	28.09	1.99	2.63	3.17	2.60	2.6	161.2	0.49	0.7	1.04	8.3	14.7	3.7
IL-10	33.08	66.39	13.91	4.60	29.49	0.99	2.16	2.14	1.76	5.4	146.9	0.55	0.6	0.91	7.9	15.4	3.2
IL-71	48.62	40.82	14.30	14.50	29.56	1.07	1.74	2.53	1.78	3.3	178.0	0.54	7.8	0.86	8.2	15.4	3.5
IL-100	55.53	28.02	13.44	23.26	30.06	1.28	1.84	2.79	1.97	3.2	167.7	0.55	6.8	1.22	7.8	15.5	3.7
IL-75	42.24	34.39	28.28	16.44	30.34	1.23	1.96	2.47	1.88	2.3	163.1	0.49	1.4	0.86	8.2	14.3	3.3
IL-1	48.11	41.62	11.09	24.32	31.29	1.04	1.70	2.44	1.73	4.1	177.9	0.48	9.1	0.99	7.7	14.7	3.6
IL-77	34.53	40.58	21.64	30.74	31.87	1.19	1.88	2.35	1.81	3.7	169.5	0.53	1.5	0.99	7.6	14.2	3.9
IL-98	36.99	31.19	24.43	46.50	34.78	1.24	1.78	2.28	1.77	2.5	161.0	0.54	1.9	0.97	8.1	14.5	3.4
IL-4	50.72	48.76	19.07	22.91	35.37	0.97	1.73	2.18	1.63	3.3	147.2	0.52	3.7	0.77	8.1	15.3	3.5
IL-7	48.59	32.06	29.49	32.70	35.71	1.17	1.76	2.37	1.77	3.2	148.1	0.49	3.8	0.96	8.0	14.1	3.7
IL-62	49.02	20.10	29.04	44.73	35.72	1.25	1.62	2.50	1.79	4.1	169.9	0.49	6.2	0.91	7.8	15.4	3.7
IL-46	35.93	56.29	35.63	15.40	35.81	1.01	1.98	2.17	1.72	2.8	158.2	0.51	3.2	1.02	8.2	15.8	3.8

Inbred line	Grain yield rank (GY-Rank) per environment					Geometric mean productivity (GMP)											
code	SHDS	MHDS	RDS	OPT	Across	SHDS vs MHDS	SHDS vs OPT	MHDS vs OPT	Average	ASI	Plant height	Ear pos.	Stem lodg.	Ears/ plant	Leaf sen.	Num. plants	Ear Asp.
	Rank	Rank	Rank	Rank	Rank	#	#	#	#	d	cm	0-1	%	#	1-10	#	1-5
IL-20	59.55	46.75	30.63	7.37	36.07	1.01	1.69	2.57	1.76	4.2	147.3	0.50	-2.8	0.92	6.1	13.2	3.1
IL-99	24.94	37.64	26.57	56.48	36.41	1.49	1.96	2.12	1.86	2.7	156.7	0.50	1.6	0.85	7.4	15.3	3.4
IL-103	57.17	38.95	15.66	34.75	36.63	1.05	1.55	2.37	1.66	3.9	179.4	0.55	4.7	1.07	7.4	13.4	3.4
IL-23	50.86	34.17	42.35	28.15	38.88	1.10	1.75	2.44	1.76	4.9	160.1	0.49	3.0	0.94	8.1	15.0	3.9
IL-22	33.97	57.71	35.57	28.30	38.89	1.16	2.09	2.07	1.77	3.3	162.8	0.43	6.8	0.81	8.4	15.3	3.5
IL-69	57.52	25.91	20.99	53.16	39.39	1.08	1.42	2.29	1.60	2.0	170.3	0.48	10.0	1.01	7.8	15.4	3.4
IL-34	65.97	25.46	14.81	52.98	39.80	0.92	1.25	2.22	1.46	3.0	160.5	0.49	5.9	0.77	7.9	14.7	2.9
IL-9	56.86	58.62	23.80	23.23	40.63	1.01	1.92	2.09	1.67	3.5	163.5	0.56	0.3	0.82	7.6	14.3	3.4
IL-38	46.25	51.50	58.25	8.83	41.21	1.08	1.96	2.50	1.85	4.3	154.8	0.53	0.5	0.96	7.1	15.4	3.8
IL-16	36.73	23.91	8.64	95.74	41.26	1.55	1.36	1.91	1.61	4.4	182.2	0.52	0.5	0.87	7.7	15.1	2.9
IL-73	46.40	53.40	45.11	21.22	41.53	1.15	2.00	2.30	1.82	4.1	156.3	0.52	1.8	0.98	7.8	14.7	3.5
IL-13	59.46	23.97	19.73	64.45	41.90	1.12	1.35	2.07	1.51	5.1	168.5	0.45	4.3	0.91	7.8	15.0	3.8
IL-54	45.17	71.20	47.22	6.47	42.51	0.91	1.89	2.15	1.65	3.1	166.8	0.47	1.9	0.84	8.2	14.3	3.6
IL-44	72.44	48.36	11.13	39.37	42.82	0.80	1.24	2.16	1.40	2.1	159.7	0.57	9.2	0.76	7.8	16.5	3.2
IL-105	34.82	81.91	24.07	32.24	43.26	0.81	1.93	1.59	1.45	2.9	157.6	0.48	0.1	0.74	7.7	16.9	3.3
IL-90	46.71	69.95	8.85	48.21	43.43	0.92	1.60	1.77	1.43	2.7	139.5	0.54	1.2	0.98	7.9	13.7	3.6
IL-55	53.83	61.32	33.50	25.80	43.61	0.82	1.49	2.02	1.45	3.7	157.5	0.55	1.8	0.78	7.9	16.2	3.8
IL-64	41.40	56.56	20.55	57.86	44.09	0.96	1.51	1.86	1.45	1.9	179.5	0.51	-1.0	0.93	8.9	16.7	3.9
IL-96	39.72	40.84	11.30	86.01	44.47	1.23	1.43	1.83	1.50	2.4	148.9	0.51	0.7	0.92	6.8	13.8	2.9
IL-51	37.76	45.45	62.98	33.99	45.04	1.11	1.80	2.20	1.71	3.3	158.0	0.50	3.2	0.96	8.1	15.6	4.1
IL-97	60.30	52.78	40.32	27.90	45.32	0.86	1.50	2.09	1.48	3.3	173.7	0.53	-1.3	0.81	7.2	14.6	3.6
IL-36	46.12	54.12	27.36	55.08	45.67	0.97	1.56	1.82	1.45	3.8	155.0	0.50	0.8	0.93	7.6	15.1	3.9
IL-49	40.48	56.12	33.37	52.74	45.68	1.04	1.64	1.88	1.52	4.8	144.9	0.53	3.7	0.86	7.9	15.6	4.0
IL-40	62.89	37.12	44.82	40.36	46.30	0.98	1.49	2.16	1.54	4.1	145.9	0.53	5.8	0.90	6.4	14.7	3.8
IL-11	31.05	56.92	41.80	61.35	47.78	1.21	1.85	1.82	1.63	2.8	165.2	0.53	3.7	0.87	8.2	15.8	3.7

Inbred line	Grain yield rank (GY-Rank) per environment					Geometric mean productivity (GMP)				ASI	Plant height	Ear pos.	Stem lodg.	Ears/ plant	Leaf sen.	Num. plants	Ear Asp.
code	SHDS	MHDS	RDS	OPT	Across	SHDS vs MHDS	SHDS vs OPT	MHDS vs OPT	Average								
	Rank	Rank	Rank	Rank	Rank	#	#	#	#	d	cm	0-1	%	#	1-10	#	1-5
IL-29	50.48	51.69	58.36	32.97	48.37	0.94	1.60	2.13	1.56	2.2	160.3	0.52	1.8	0.83	8.6	16.7	3.8
IL-2	45.14	50.40	58.31	41.31	48.79	1.05	1.59	2.19	1.61	5.0	164.5	0.51	14.7	0.82	8.2	14.5	3.4
IL-80	64.63	48.72	34.55	50.39	49.57	0.83	1.28	2.06	1.39	4.4	172.7	0.53	14.9	0.93	6.5	14.9	4.1
IL-81	54.56	53.21	11.28	83.88	50.73	1.03	1.33	1.62	1.33	2.4	173.3	0.50	3.8	0.89	7.3	14.5	4.2
IL-68	68.59	53.03	23.91	58.04	50.89	0.82	1.25	1.86	1.31	2.6	147.2	0.52	-0.2	0.80	7.9	14.0	3.6
IL-82	62.80	38.77	62.68	41.31	51.39	0.99	1.48	2.15	1.54	3.6	157.7	0.52	5.9	1.02	7.3	14.1	3.7
IL-60	61.37	29.09	43.31	76.87	52.66	1.08	1.24	2.03	1.45	4.1	154.1	0.57	-2.2	0.89	6.6	15.3	4.2
IL-35	63.19	59.48	25.75	65.57	53.50	0.83	1.24	1.81	1.30	2.6	151.9	0.48	3.3	0.90	7.6	13.7	3.8
IL-48	63.04	38.96	44.84	68.82	53.91	1.00	1.27	2.13	1.47	3.0	170.2	0.54	0.8	0.85	8.1	14.2	3.7
IL-8	56.48	65.92	27.83	66.43	54.16	0.77	1.25	1.58	1.20	3.8	151.3	0.50	7.8	0.87	8.0	14.1	4.3
IL-72	74.73	71.32	23.14	47.64	54.21	0.65	1.17	1.73	1.18	6.2	155.2	0.49	5.8	0.72	7.7	15.4	3.7
IL-5	79.11	40.06	44.02	56.60	54.95	0.76	1.04	2.08	1.29	3.9	150.1	0.53	4.1	0.93	7.9	14.4	3.7
IL-42	59.02	29.32	56.32	75.33	55.00	0.91	1.13	1.94	1.33	3.2	162.4	0.51	2.9	0.93	8.5	14.6	3.9
IL-59	73.10	47.98	46.75	54.71	55.63	0.74	1.16	1.92	1.27	2.9	149.5	0.53	9.4	0.81	6.4	14.9	4.0
IL-27	63.70	86.32	57.40	16.16	55.90	0.51	1.44	1.51	1.15	5.0	161.4	0.48	3.9	0.76	7.5	14.8	4.0
IL-93	68.04	50.30	31.98	73.79	56.03	0.78	1.11	1.79	1.22	2.1	141.1	0.49	12.1	0.95	6.0	13.7	4.1
IL-86	50.33	53.65	51.06	71.51	56.64	1.04	1.38	1.90	1.44	3.3	178.0	0.47	1.0	0.77	6.1	13.4	3.9
IL-89	67.04	72.08	50.85	42.67	58.16	0.64	1.27	1.68	1.20	2.6	153.4	0.50	4.0	0.88	7.0	14.2	3.8
IL-15	74.16	43.73	50.48	69.01	59.34	0.85	1.14	1.94	1.31	4.9	157.8	0.48	8.9	0.78	8.3	14.3	3.7
IL-78	66.03	75.79	55.95	39.72	59.37	0.60	1.29	1.66	1.19	4.9	147.6	0.52	5.1	0.81	8.4	15.1	3.8
IL-63	80.76	28.58	47.23	82.06	59.66	0.77	0.87	1.88	1.18	4.9	140.0	0.47	4.0	0.79	6.4	15.2	4.2
IL-21	44.28	48.02	87.80	62.65	60.69	0.98	1.43	1.86	1.42	3.8	170.9	0.50	9.2	0.82	8.5	15.2	4.3
IL-57	77.91	50.23	42.57	78.42	62.28	0.71	1.00	1.80	1.17	3.1	156.6	0.51	4.1	1.07	6.4	15.0	4.2
IL-104	60.96	52.89	67.31	71.72	63.22	0.85	1.21	1.78	1.28	3.1	151.9	0.47	0.9	0.87	7.9	16.1	3.8
IL-30	30.09	80.40	68.63	78.17	64.32	0.89	1.61	1.35	1.28	3.6	165.3	0.51	1.0	0.87	8.1	14.3	3.8

Inbred line	Grain yield rank (GY-Rank) per environment					Geometric mean productivity (GMP)				ASI	Plant height	Ear pos.	Stem lodg.	Ears/ plant	Leaf sen.	Num. plants	Ear Asp.
code	SHDS	MHDS	RDS	OPT	Across	SHDS vs MHDS	SHDS vs OPT	MHDS vs OPT	Average								
	Rank	Rank	Rank	Rank	Rank	#	#	#	#	d	cm	0-1	%	#	1-10	#	1-5
IL-74	73.57	62.47	50.89	70.71	64.41	0.62	0.93	1.66	1.07	4.1	158.0	0.52	7.2	0.85	8.3	13.0	3.7
IL-24	88.21	71.49	53.26	45.00	64.49	0.46	0.87	1.72	1.02	5.6	148.4	0.48	1.1	0.81	7.2	14.6	3.8
IL-66	65.77	65.23	55.88	72.82	64.93	0.65	1.06	1.48	1.06	5.6	160.5	0.50	2.6	0.85	8.1	14.8	3.5
IL-25	61.68	40.24	68.50	89.58	65.00	0.92	0.95	1.53	1.13	4.6	165.0	0.49	5.6	0.85	8.5	14.9	3.9
IL-106	64.57	76.47	63.27	66.32	67.66	0.68	1.32	1.47	1.16	5.4	168.4	0.52	3.0	1.01	8.5	14.8	3.9
IL-84	60.42	74.47	53.14	91.21	69.81	0.78	1.04	1.08	0.96	3.8	144.6	0.56	19.8	0.84	4.7	13.1	3.8
IL-50	52.85	79.08	76.16	74.06	70.54	0.73	1.27	1.37	1.12	2.8	168.6	0.47	-0.3	0.88	7.9	14.7	3.9
IL-6	73.78	63.49	77.34	71.58	71.55	0.62	0.98	1.58	1.06	4.3	151.7	0.46	2.2	0.75	8.3	15.2	3.8
IL-70	64.00	67.21	73.53	81.63	71.59	0.75	1.07	1.53	1.12	4.2	145.1	0.50	2.4	0.81	7.8	14.6	4.0
IL-91	64.70	73.51	85.15	64.35	71.93	0.62	1.08	1.50	1.07	2.3	142.5	0.52	2.1	0.78	7.8	15.6	4.1
IL-88	82.46	65.84	88.32	52.93	72.39	0.49	0.82	1.83	1.05	4.8	177.4	0.47	4.1	0.79	6.4	13.1	3.9
IL-79	67.89	84.77	79.79	58.89	72.83	0.67	1.25	1.54	1.16	3.2	160.9	0.47	3.6	0.82	8.0	15.1	4.0
IL-52	90.14	68.94	73.92	58.68	72.92	0.46	0.86	1.56	0.96	4.2	157.3	0.50	3.0	0.86	7.9	12.1	4.0
IL-94	85.27	67.70	84.70	55.47	73.28	0.42	0.76	1.62	0.93	3.4	137.4	0.47	-1.7	0.76	6.1	16.4	4.5
IL-85	45.73	66.33	87.16	94.83	73.51	0.95	1.29	1.38	1.21	3.0	168.8	0.53	-0.1	0.87	5.8	12.4	3.8
IL-18	89.06	72.01	65.21	69.13	73.85	0.51	0.89	1.49	0.96	2.9	151.2	0.52	13.0	1.03	9.0	14.9	4.4
IL-41	82.01	54.38	68.34	93.13	74.46	0.69	0.82	1.41	0.97	6.0	161.0	0.50	0.8	0.70	7.7	15.0	3.8
IL-3	68.18	69.02	85.32	78.85	75.34	0.71	1.09	1.50	1.10	3.7	167.2	0.54	1.3	0.84	7.9	14.3	3.5
IL-56	68.72	59.85	77.60	98.15	76.08	0.75	0.88	1.33	0.99	3.8	178.4	0.49	5.7	0.83	8.4	13.4	3.6
IL-19	44.63	92.79	90.31	77.89	76.40	0.72	1.38	1.25	1.12	3.7	146.2	0.45	14.4	0.79	8.3	12.6	4.2
IL-45	71.75	86.39	86.17	66.02	77.58	0.57	1.10	1.40	1.02	5.2	167.4	0.52	1.6	0.75	8.2	13.6	3.8
IL-58	76.99	79.81	63.03	91.58	77.85	0.50	0.79	1.27	0.85	4.9	154.8	0.52	1.3	0.78	8.1	14.8	4.0
IL-39	67.57	79.07	71.09	98.07	78.95	0.48	0.70	1.26	0.81	4.8	161.3	0.53	4.0	0.79	8.5	13.9	3.9
IL-67	60.37	68.55	85.10	101.79	78.95	0.79	0.92	1.07	0.93	3.8	162.2	0.52	-0.9	0.73	6.3	14.5	4.0
IL-65	63.78	89.41	79.29	84.37	79.21	0.52	1.00	1.07	0.86	5.6	168.2	0.47	-2.1	0.58	7.7	15.4	4.1

Inbred line	Grain yield rank (GY-Rank) per environment					Geometric mean productivity (GMP)				ASI	Plant height	Ear pos.	Stem lodg.	Ears/ plant	Leaf sen.	Num. plants	Ear Asp.
code	SHDS	MHDS	RDS	OPT	Across	SHDS vs MHDS	SHDS vs OPT	MHDS vs OPT	Average								
	Rank	Rank	Rank	Rank	Rank	#	#	#	#	d	cm	0-1	%	#	1-10	#	1-5
IL-14	96.40	85.63	71.00	65.61	79.66	0.35	0.66	1.40	0.81	3.2	146.5	0.52	3.4	0.60	8.6	14.4	3.8
IL-12	68.12	72.83	89.16	89.45	79.89	0.68	0.96	1.21	0.95	5.3	152.0	0.49	-0.7	0.87	8.4	14.3	4.0
IL-87	102.77	93.27	79.62	50.53	81.55	0.21	0.48	1.32	0.67	3.4	146.0	0.47	4.2	1.01	5.0	14.1	4.2
IL-37	61.74	88.61	96.70	84.53	82.89	0.51	1.09	1.07	0.89	3.1	145.1	0.49	-0.3	0.75	8.5	14.6	4.4
IL-28	75.61	89.02	79.13	90.43	83.55	0.45	0.72	1.05	0.74	3.2	154.3	0.47	6.3	0.77	7.8	12.8	4.1
IL-61	62.10	80.18	95.07	107.65	86.25	0.62	0.83	0.97	0.81	3.9	157.9	0.46	-0.8	0.85	8.1	15.0	3.8
IL-95	59.53	84.88	102.43	106.70	88.38	0.60	0.41	0.44	0.48	NE	132.5	0.51	0.8	0.51	7.9	13.9	4.7
IL-83	81.85	77.90	100.32	93.66	88.43	0.54	0.77	1.03	0.78	3.6	155.0	0.54	4.9	0.71	4.9	13.3	4.3
IL-26	95.35	78.13	90.88	93.86	89.55	0.40	0.56	1.09	0.68	4.6	176.4	0.50	2.3	0.63	7.9	12.6	3.8
IL-32	80.92	79.62	102.74	95.25	89.63	0.53	0.81	1.22	0.85	5.3	151.9	0.51	4.5	0.62	7.4	14.8	3.9
Mean	**57.02**	**54.10**	**47.25**	**53.39**	**53.81**	-	-	-	-	**3.30**	**152.34**	**0.50**	**3.61**	**0.77**	**7.23**	**14.51**	**3.82**
LSD (0.05)	**40.56**	**37.53**	**38.02**	**33.96**	**16.82**	-	-	-	-	**2.25**	**13.54**	**0.06**	**7.20**	**0.14**	**0.76**	**1.28**	**0.37**
SE	**20.46**	**18.93**	**19.18**	**17.13**	**8.53**	-	-	-	-	**1.14**	**6.87**	**0.03**	**3.63**	**0.07**	**0.38**	**0.65**	**0.19**
p	**	***	***	***	***	-	-	-	-	**ns**	***	**ns**	**ns**	***	***	***	***
Min	**14.39**	**2.48**	**-7.37**	**-6.32**	**6.44**	**0.21**	**0.41**	**0.44**	**0.48**	**1.31**	**132.48**	**0.43**	**-2.80**	**0.51**	**4.65**	**12.11**	**2.74**
Max	**102.77**	**93.27**	**102.74**	**107.65**	**89.63**	**2.20**	**2.88**	**4.56**	**3.21**	**6.20**	**182.16**	**0.59**	**19.75**	**1.22**	**9.02**	**16.88**	**4.68**

Appendices from chapter 3

Appendix 0-1. General and specific combining ability effects for grain yield and other traits of ten maize inbreds evaluated under non-stressed conditions in Chókwè 2015.

Parent/cross	GY	W100G	NGPE	NGPP	GWPE	GWPP	GT	AD	PH	EPO	BHC	EA
					Parents GCA effects estimates							
P1	-0.302**	0.433	-26.429**	-25.716*	-6.475	-8.358**	-0.233**	-1.217*	-8.828***	-0.014*	0.253	0.054
P2	0.242*	-2.758***	74.275***	74.622***	9.558*	10.422***	-0.233**	-0.258	0.814	0.006	-0.380*	-0.488***
P3	-0.120	0.221	4.558	-4.333	0.317	2.747	0.100	-0.300	1.685	0.001	0.265	0.158
P4	0.242*	0.483	18.092*	15.034	7.271	10.493***	-0.150	0.950	5.914*	0.032***	0.126	-0.175
P5	-0.724***	1.421***	-68.296***	-82.970***	-18.863***	-16.178***	-0.025	-0.758	-11.244***	-0.014*	1.090***	0.367***
P6	-0.029	-1.763***	7.167	25.555*	-0.867	-8.691**	0.038	1.658**	13.706***	0.007	-0.347	0.138
P7	-0.387***	-0.738	-4.092	-7.683	-5.408	-5.116	0.183*	0.450	5.781*	0.005	-0.118	0.283**
P8	-0.344**	-0.596	-35.488***	-19.308	-8.158*	-15.133***	-0.067	-0.008	-10.086***	-0.011	-0.203	0.263*
P9	0.932***	0.196	59.592***	47.030***	15.046***	23.955***	0.538***	0.533	8.814***	0.005	-0.260	-0.425***
P10	0.489***	3.100***	-29.379***	-22.233	7.579	5.859*	-0.150	-1.050*	-6.557**	-0.015	-0.426*	-0.175
					Crosses SCA effects estimates							
P1 × P2	1.013***	0.029	20.843	8.265	3.343	10.814	0.370	0.431	0.270	0.018	-0.559	0.148
P1 × P3	-0.571*	-0.417	-24.440	-6.214	-3.149	-7.877	0.204	0.472	3.066	0.015	0.195	0.002
P1 × P4	-0.154	-1.213	35.760	11.619	-0.503	9.110	-0.380	-0.778	-9.763	0.005	1.468**	-0.331
P1 × P5	0.273	2.516*	35.181	21.924	16.363	22.414**	-0.005	-0.403	-4.671	-0.040*	0.270	-0.206
P1 × P6	-0.183	-2.934**	2.785	61.899	4.801	-11.006	-0.234	1.181	5.379	-0.004	0.175	0.023
P1 × P7	-0.661*	0.241	-36.224	-45.264	-14.024	-14.915*	0.120	-1.944	-0.963	-0.009	-0.655	0.544
P1 × P8	0.009	0.566	-57.828*	-50.106	-12.207	-20.865**	0.204	2.847*	9.837	0.017	-0.669	0.565*
P1 × P9	-0.037	0.308	18.693	2.524	3.355	11.448	-0.234	-1.694	-0.330	0.022	-0.246	-0.248
P1 × P10	0.310	0.904	5.231	-4.647	2.022	0.877	-0.046	-0.111	-2.825	-0.025	0.020	-0.500
P2 × P3	-0.798**	-0.359	67.589**	-42.851	-13.882	17.677*	0.704**	-0.153	-9.909	0.017	0.062	-0.289
P2 × P4	0.583*	1.612	96.356***	163.449***	55.130***	44.198***	0.454*	-0.403	6.462	0.023	0.202	0.211
P2 × P5	-0.738*	-2.759*	-32.490	-37.281	-20.003	-25.498**	-0.338	2.639	8.554	-0.018	0.704	0.002
Parent/cross	GY	W100G	NGPE	NGPP	GWPE	GWPP	GT	AD	PH	EPO	BHC	EA

non-stressed (Cont.)

	Crosses SCA effects estimates											
P2 × P6	-1.430***	-0.209	-41.319	-77.606*	-24.466*	-17.186*	-0.234	-3.111*	-8.996	0.008	0.341	0.231
P2 × P7	0.162	3.133**	-78.994***	-39.635	3.409	-8.227	-0.213	0.097	7.062	-0.014	-0.188	-0.250
P2 × P8	-0.011	-1.042	-29.365	18.890	-1.741	-13.144	-0.296	-1.444	-2.871	-0.011	0.264	0.106
P2 × P9	0.186	-0.367	-4.744	7.853	-2.645	-10.331	-0.234	0.014	-1.971	-0.020	-0.380	0.127
P2 × P10	1.033***	-0.038	2.126	-1.085	0.855	1.698	-0.213	1.931	1.400	-0.003	-0.446	-0.289
P3 × P4	0.608*	-1.767	3.539	27.703	-0.228	-6.561	0.120	-1.028	-2.275	-0.030	-0.011	0.398
P3 × P5	0.051	-0.771	-20.107	-33.860	-14.795	-15.056*	-0.338	0.681	14.950*	0.008	-0.775	0.190
P3 × P6	0.459	2.979**	-26.369	-15.618	7.543	3.056	-0.067	0.931	0.933	-0.035*	-0.805	-0.248
P3 × P7	-0.786**	-0.913	-24.244	-18.947	-9.349	-12.319	-0.213	1.139	-9.809	0.003	0.566	0.273
P3 × P8	0.568*	2.145*	-15.215	0.844	9.734	7.664	-0.463*	-3.069*	-5.609	-0.011	-0.915	-0.873
P3 × P9	0.891**	0.254	36.139	47.440	15.997	15.277*	0.100	2.056	8.159	0.013	0.875	0.481
P3 × P10	-0.422	-1.150	3.110	41.503	8.130	-1.861	-0.046	-1.028	0.495	0.020	0.808	0.065
P4 × P5	-0.388	-0.400	1.026	-2.260	-2.216	-1.236	-0.088	-0.236	-8.480	0.021	0.064	-0.144
P4 × P6	0.260	0.516	-5.036	-31.785	-6.478	-0.856	0.350	0.014	-0.230	-0.002	0.535	0.086
P4 × P7	0.238	0.091	-56.178*	-34.681	-10.237	-20.731**	-0.130	-0.778	9.162	0.006	-0.661	0.106
P4 × P8	-0.502	-0.184	-36.982	-48.756	-15.287	-17.781*	-0.046	1.347	0.429	-0.002	-0.093	-0.039
P4 × P9	-0.358	0.291	-21.028	-62.993*	-17.057	-4.902	0.016	0.139	5.262	-0.000	-0.986*	-0.019
P4 × P10	-0.288	1.054	-17.457	-22.297	-3.124	-1.240	-0.296	1.722	-0.567	-0.020	-0.519	-0.269
P5 × P6	1.003***	0.979	-5.749	-22.714	-1.678	4.748	-0.109	0.389	-6.605	0.040*	-1.296**	0.044
P5 × P7	0.818**	2.054	61.676**	98.824**	39.563***	36.073***	0.245	-0.403	-6.346	0.001	2.307***	0.23
P5 × P8	-0.142	-0.621	19.972	3.315	-1.387	6.056	0.329	-2.278	-0.080	-0.009	-0.673	-0.081
P5 × P9	-0.252	0.420	-47.907*	15.211	7.276	-15.631*	0.058	0.181	1.554	0.005	-0.517	-0.227
P5 × P10	-0.625*	-1.417	-11.603	-43.160	-23.124*	-11.869	0.245	-0.569	1.125	-0.008	-0.084	0.190
P6 × P7	0.153	-3.296**	77.381***	38.465	-5.599	4.719	0.016	1.847	-7.296	0.011	-0.488	0.461
P6 × P8	-0.027	1.195	7.910	-0.943	5.818	8.802	0.100	-0.361	7.037	-0.007	0.964	-0.019
P6 × P9	-0.120	-0.863	15.997	20.586	1.080	3.514	-0.171	0.097	3.070	-0.022	0.187	-0.331
P6 × P10	-0.114	1.633	-25.599	27.715	18.980	4.210	0.350	-0.986	6.708	0.011	0.387	-0.248
Parent/cross	GY	W100G	NGPE	NGPP	GWPE	GWPP	GT	AD	PH	EPO	BHC	EA

non-stressed (cont.)

					Crosses SCA effects estimates							
P7 × P8	-0.149	-0.163	24.068	10.661	3.226	6.794	-0.046	0.514	0.962	0.005	-0.232	-0.664
P7 × P9	0.425	0.579	4.022	-2.110	3.488	8.406	0.350	-0.028	2.929	-0.007	-0.242	-0.644
P7 × P10	-0.202	-1.725	28.493	-7.314	-10.478	0.202	-0.130	-0.444	4.300	0.003	-0.409	-0.060
P8 × P9	-0.395	-1.630	35.285	14.149	-3.195	3.356	0.100	1.097	-8.871	0.002	1.210	0.377
P8 × P10	0.648*	-0.267	52.156*	51.944	15.038	19.119*	0.120	1.347	-0.834	0.016	0.143	0.627
P9 × P10	-0.341	1.008	-36.457	-42.660	-8.299	-11.136	0.016	-1.861	-9.800	0.007	0.100	0.481

* = significant at 0.05; ** = Significant at 0.01; *** = significant at 0.001.

Appendix 0-2. General and specific combining ability effects for grain yield and other traits of ten maize inbreds evaluated under isolated drought stress conditions in Chókwè 2015.

Parent/cross	GY	NP	W100G	NGPE	NGPP	GWPE	GWPP	AD	PH
				Parents GCA effects estimates					
P1	-0.532***	0.233	-1.237***	-51.933***	-63.733***	-20.625***	-23.850***	-0.642**	-8.895**
P2	0.077	0.067	-1.658***	29.650***	38.892***	1.917	4.525	0.150	4.855
P3	0.032	-1.392	1.488***	23.733***	4.017	13.500***	7.567	0.608*	7.401*
P4	0.092	0.192	2.138***	-36.683***	-19.817	-3.250	2.775	0.650**	2.676
P5	-0.169**	-0.600	1.113***	-15.975*	-31.817**	-0.333	-5.225	-0.433	-10.883**
P6	0.039	1.483*	-1.595***	-18.808*	5.558	-11.833***	-5.392	0.317	1.001
P7	0.251***	0.733	-0.341	23.775**	27.475*	5.583*	6.233	-0.350	3.901
P8	-0.119*	0.692	-1.974***	-3.433	0.683	-8.792***	-7.683*	0.775**	-0.737
P9	0.471***	0.608	0.422	71.567***	48.642***	23.708***	16.567***	0.525*	5.051
P10	-0.143*	-2.017**	1.643***	-21.892**	-9.900	0.125	4.483	-1.600***	-4.370
				Crosses SCA effects estimates					
P1 × P2	0.612***	3.315	0.565	54.528**	27.819	19.042**	11.014	-0.819	5.393
P1 × P3	0.350*	2.773	0.619	-12.222	1.361	-1.875	1.972	0.056	0.947
P1 × P4	0.449**	-1.144	3.036***	37.861	41.861	22.875***	24.431**	1.014	8.805
P1 × P5	-0.588***	-4.352*	-0.972	-23.847	-25.806	-12.375	-11.903	0.097	-0.303
P1 × P6	-0.237	1.565	-3.931***	28.986	6.819	-5.542	-12.403	-0.653	-12.753
Parent/cross	GY	NP	W100G	NGPE	NGPP	GWPE	GWPP	AD	PH

Isolated drought (cont.)

Crosses SCA effects estimates

P1 × P7	0.368*	-0.685	0.915	5.736	52.903	5.708	19.972*	-1.653**	-1.187
P1 × P8	-0.387*	-3.977*	-0.785	6.611	4.361	-0.250	-1.111	0.889	-3.249
P1 × P9	-0.372*	-2.894	1.886*	-57.722**	-35.931	-10.417	-3.694	1.139	-1.537
P1 × P10	-0.196	5.398**	-1.335	-39.931*	-73.389*	-17.167**	-28.278**	-0.069	3.884
P2 × P3	-0.087	-2.394	-0.160	70.528***	28.069	20.583**	7.597	-0.403	1.463
P2 × P4	0.180	-4.310*	0.024	-6.722	92.236**	-1.333	28.722**	0.556	3.888
P2 × P5	0.504**	4.148*	-1.051	-1.097	18.903	-4.583	1.056	0.639	14.547
P2 × P6	0.052	-0.602	3.457***	-27.931	-43.472	5.583	1.889	0.222	-7.270
P2 × P7	-0.921***	-1.185	1.103	-61.514**	-130.722***	-13.500*	-33.736***	0.556	-19.137*
P2 × P8	-0.606***	1.523	-1.864*	-51.972*	-85.264**	-22.792***	-32.819***	0.431	4.334
P2 × P9	-0.254	-3.394	-0.826	8.361	41.111	-2.625	7.597	-0.319	-4.253
P2 × P10	0.521***	2.898	-1.247	15.819	51.319	-0.375	8.681	-0.861	1.034
P3 × P4	-1.179***	-7.185***	-1.222	-40.472*	-45.889	-17.250**	-19.319*	0.764	-6.257
P3 × P5	0.390*	2.940	1.669*	2.819	-6.556	8.500	4.681	-0.153	1.134
P3 × P6	0.886***	3.856*	1.144	49.986*	45.403	20.333**	19.847*	0.431	24.118**
P3 × P7	0.163	1.606	2.024**	-37.264	-35.514	-3.417	-1.778	0.431	2.818
P3 × P8	-0.009	0.315	-1.043	1.944	21.944	-4.375	2.139	-0.028	-21.545*
P3 × P9	0.363*	6.398**	-0.539	-64.389**	-44.014	-21.208**	-14.778	-0.778	-4.499
P3 × P10	-0.877***	-8.310***	-2.493**	29.069	35.194	-1.292	-0.361	-0.319	1.822
P4 × P5	0.382*	5.023*	0.186	-5.764	-11.056	-2.417	-4.194	-0.528	1.493
P4 × P6	0.363*	1.606	-0.072	53.736**	19.903	16.750*	6.639	-0.944	-6.757
P4 × P7	-0.131	-0.644	-0.126	-10.847	-10.347	-3.000	-2.653	-0.944	-3.991
P4 × P8	-0.164	2.398	-0.926	-3.972	-42.556	-4.292	-16.736	-0.069	2.480
P4 × P9	-0.312*	2.148	-1.222	-29.972	-58.514*	-13.458*	-22.986*	0.181	-0.307
P4 × P10	0.412**	2.106	0.324	6.153	14.361	2.125	6.097	-0.028	0.647
P5 × P6	-0.458**	-1.269	-0.181	-17.306	-47.431	-5.167	-14.028	-0.861	-9.032
P5 × P7	-0.775***	-9.519***	-0.435	17.111	48.986	3.750	14.681	0.472	-15.466
Parent/cross	GY	NP	W100G	NGPE	NGPP	GWPE	GWPP	AD	PH

Isolated drought (cont.)

				Crosses SCA effects estimates					
P5 × P8	0.812***	1.190	0.999	67.986**	79.111**	24.792***	28.264**	0.347	6.138
P5 × P9	-0.110	-0.060	0.503	-7.014	-21.181	1.292	-3.653	-0.069	2.051
P5 × P10	-0.156	1.898	-0.718	-32.889	-34.972	-13.792*	-14.903	0.056	-0.562
P6 × P7	-0.195	-1.269	-3.960***	4.278	70.278*	-15.750*	-0.486	1.389*	4.918
P6 × P8	0.093	-0.227	1.740*	-45.847*	-8.264	-6.042	4.431	-0.736	1.555
P6 × P9	-0.246	0.856	-0.656	-13.847	-36.222	-8.208	-14.153	-0.153	10.968
P6 × P10	-0.259	-4.519	2.457**	-32.056	-7.014	-1.958	8.264	1.306*	-5.745
P7 × P8	0.152	3.190	1.319	-17.764	-40.181	-0.125	-6.194	0.597	17.488*
P7 × P9	0.850***	2.273	-1.143	114.236***	83.528	29.375***	20.222*	-0.153	5.334
P7 × P10	0.489**	6.231**	0.303	-13.972	-38.931	-3.042	-10.028	-0.694	9.222
P8 × P9	0.062	-2.019	-0.076	12.778	44.319	1.417	11.472	-0.944	-2.328
P8 × P10	0.047	-2.394	0.636	30.236	26.528	11.667	10.556	-0.486	-4.874
P9 × P10	0.019	-3.310	2.074**	37.569	26.903	23.833***	19.972*	1.097	-5.428

* = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001.

Appendix 0-3. General and specific combining ability effects for grain yield and other traits of ten maize inbreds evaluated under isolated heat stress conditions in Chókwè 2015.

Parent/cross	GY	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT	AD	ASI	PH	EPO	BHC
						Parents GCA effects estimates							
P1	-0.094	0.005	-0.804**	10.025	13.083	-0.958	-0.383	-0.104	-1.142***	-0.425	-9.813**	-0.025***	2.590
P2	0.181	0.043*	-2.321***	46.900***	59.083***	2.500	6.242*	-0.416***	0.650*	0.867**	2.546	0.016**	-11.723***
P3	0.572***	0.010	1.783***	29.608***	30.875***	15.250***	15.408***	0.229**	0.358	0.033	12.104**	0.014*	2.490
P4	-0.419**	-0.041*	0.983***	-45.017***	-57.708***	-8.458***	-12.050***	-0.375***	0.900***	-0.342	0.304	0.037***	3.236
P5	-0.467***	-0.036	0.458	-32.183***	-44.542***	-7.125***	-10.383***	-0.104	-0.767**	-0.008	-4.471	-0.022***	13.982***
P6	-0.035	0.038*	-1.508***	3.900	19.542*	-4.458**	0.117	0.000	1.108***	1.242***	3.813	0.019**	0.515
P7	-0.040	-0.005	0.375	-5.183	-6.917	0.167	-0.508	0.333***	-0.350	0.117	2.558	0.026***	-12.377***
P8	-0.284*	-0.012	0.1208333	-29.642***	-31.208***	-6.958***	-7.550**	0.104	0.400	0.492	-8.525*	-0.027***	-0.256
P9	0.539***	-0.016	-0.929*	54.900***	44.042***	11.208***	8.867***	0.479***	0.483	0.325	8.225*	0.002	12.219***
P10	0.047	0.013	1.842***	-33.308***	-26.250**	-1.167	0.242	-0.146*	-1.642***	-2.300***	-6.742	-0.041***	-10.677***

Parent/cross	GY	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT	AD	ASI	PH	EPO	BHC
Isolated heat (cont.)													
						Crosses SCA effects estimates							
P1 × P2	0.285	0.058	-1.623*	34.912*	62.167**	1.088	7.394	0.336	-0.005	-0.523	-4.144	0.010	12.175*
P1 × P3	0.167	-0.049	2.039**	-16.796	-39.625	4.671	-2.440	0.023	-0.380	-0.356	1.131	-0.014	-5.270
P1 × P4	0.184	0.042	1.373	-8.838	3.625	3.380	6.685	-0.373*	0.412	0.685	2.997	0.029	25.917***
P1 × P5	-1.078**	-0.110	-2.769***	-29.005	-64.208**	-15.620***	-22.981***	0.023	-0.255	-0.315	-9.294	-0.005	-21.429***
P1 × P6	1.143***	0.079	-1.169	97.579***	130.708***	18.713***	26.519***	-0.081	0.537	1.765	-3.244	-0.019	-0.629
P1 × P7	-0.355	-0.002	0.614	-26.671	-28.167	-3.912	-4.523	0.086	-0.671	-1.106	-8.524	-0.033	-17.437**
P1 × P8	-0.018	-0.004	1.835*	-38.546*	-40.875	-3.454	-4.148	0.148	-0.088	-0.481	9.860	0.033	9.342
P1 × P9	-0.437	-0.010	-0.148	-25.421	-31.792	-7.620	-8.231	-0.060	-0.171	-0.315	4.876	-0.016	-2.500
P1 × P10	0.108	-0.003	-0.152	12.787	8.167	2.755	1.727	-0.102	0.620	0.645	6.343	0.014	-0.170
P2 × P3	-0.541	-0.064	-2.111**	21.329	-5.958	-4.120	-10.065	0.502**	0.829	-1.315	-5.194	0.022	-11.625*
P2 × P4	0.349	0.044	1.923**	-18.713	-3.375	3.588	8.060	-0.060	0.620	-0.273	12.638	-0.008	20.730***
P2 × P5	0.131	0.039	-1.686*	10.787	24.792	-3.745	0.394	0.002	0.954	0.727	-1.186	-0.006	-5.983
P2 × P6	-0.998**	-0.058	0.581	-65.296***	-85.958***	-13.745***	-19.773**	-0.102	-0.255	0.810	-10.703	0.040	-6.750
P2 × P7	0.264	0.014	1.598	17.787	24.167	11.630**	13.185*	-0.435*	0.204	0.935	8.251	0.006	0.342
P2 × P8	-0.192	-0.005	0.919	-53.088***	-55.542*	-8.912*	-10.106	-0.206	-1.546	-0.106	7.435	-0.028	-3.645
P2 × P9	1.295***	-0.007	0.869	88.370***	81.208***	24.255***	22.477***	0.086	-0.963	-0.273	4.785	-0.010	-3.954
P2 × P10	-0.593	-0.020	-0.469	-36.088*	-41.500	-10.037*	-11.565	-0.123	0.162	0.019	-11.882	-0.027	-1.291
P3 × P4	-1.116**	0.021	-1.215	-74.088***	-60.833**	-25.829***	-22.106***	0.127	0.245	1.227	-15.519	-0.015	-9.183
P3 × P5	-0.284	-0.008	0.677	-29.588*	-31.333	-5.829	-7.440	-0.310	1.245	1.227	10.922	0.013	17.305**
P3 × P6	1.227***	0.081	2.777***	17.329	51.583*	16.838***	26.727***	0.419*	0.370	-0.690	14.506	0.022	5.471
P3 × P7	-0.568	-0.046	-0.706	-24.588	-41.625	-9.787*	-14.648*	-0.414*	-0.505	-0.898	6.193	-0.001	14.130*
P3 × P8	1.056**	0.014	-1.119	117.537***	114.667***	27.671***	27.394***	-0.352	-0.588	0.727	-5.257	-0.015	-7.158
P3 × P9	0.594	0.056	0.798	-3.338	23.083	3.838	10.310	0.440*	-0.338	0.227	7.193	0.002	3.700
P3 × P10	-0.535	-0.004	-1.140	-7.796	-9.958	-7.454	-7.731	-0.435*	-0.880	-0.148	-13.974	-0.018	-7.370
P4 × P5	0.430	-0.004	1.444*	45.370**	43.917	17.213***	15.352*	0.127	-0.296	-0.731	6.856	-0.014	-5.175
P4 × P6	-0.422	-0.057	-1.256	-18.713	-39.833	-8.787*	-13.482*	-0.144	-0.171	-0.315	1.272	-0.008	-9.875
Parent/cross	GY	EPP	W100G	NGPE	NGPP	GWPE	GWPP	GT	AD	ASI	PH	EPO	BHC

Isolated heat (cont.)

						Crosses SCA effects estimates						
P4 × P7	-0.107	-0.055	-1.806*	28.037	5.292	0.921	-4.190	0.190	-0.380	-0.856	-4.407	0.002	2.717
P4 × P8	-0.250	-0.004	0.348	0.829	1.917	0.380	0.519	0.419	0.204	0.435	-6.090	-0.005	-3.204
P4 × P9	0.014	-0.013	0.431	-0.713	-6.000	2.213	-0.231	-0.289	-0.880	-0.731	1.426	0.002	-13.512*
P4 × P10	0.919**	0.027	-1.240	46.829**	55.292*	6.921	9.394	0.002	0.245	0.560	0.826	0.015	-8.416
P5 × P6	-0.564	-0.003	1.035	-80.880***	-78.333***	-17.120***	-16.815**	-0.081	-0.838	0.352	-5.419	-0.005	8.446
P5 × P7	-0.032	0.006	0.452	-3.796	1.792	0.588	1.477	0.086	-0.380	0.144	-7.665	-0.019	12.471*
P5 × P8	1.388***	0.060	3.173***	42.995**	60.750**	23.380***	27.852***	0.148	-0.463	-1.565	12.018	0.027	-2.383
P5 × P9	-0.701*	-0.052	-2.644***	16.454	-7.833	-6.454	-11.898	0.106	0.454	0.269	-14.099	0.018	3.509
P5 × P10	0.711*	0.072	0.319	27.662	50.458*	7.588	14.060*	-0.102	-0.421	-0.106	7.868	-0.009	-6.762
P6 × P7	0.569	0.066	-0.615	34.787*	56.708*	6.255	11.977	0.315	0.079	-0.440	9.485	0.007	-12.795*
P6 × P8	0.386	-0.027	-1.094	73.912***	54.667*	14.046***	9.019	-0.123	-0.005	-1.148	8.768	-0.004	-2.750
P6 × P9	-1.440***	-0.056	-2.577***	-78.630***	-95.583***	-30.120***	-33.731***	-0.498**	0.245	-0.315	-13.349	-0.010	4.242
P6 × P10	0.099	-0.025	2.319**	19.912	6.042	13.921***	9.560	0.294	0.037	-0.023	-1.315	-0.023	14.638**
P7 × P8	-0.569	-0.008	-0.477	-54.005***	-52.875*	-16.579***	-16.023*	-0.123	1.787	1.977	-13.678	0.009	5.075
P7 × P9	0.249	0.010	0.073	3.787	7.208	1.588	2.227	0.336	0.370	0.810	1.839	0.003	-3.266
P7 × P10	0.550	0.014	0.869	24.662	27.500	9.296*	10.519	-0.039	-0.505	-0.565	8.506	0.027	-1.237
P8 × P9	-0.057	0.054	0.060	-1.088	21.500	-0.620	5.269	-0.269	0.620	0.435	-4.678	-0.014	2.946
P8 × P10	-1.742***	-0.079	-3.644***	-88.546***	-104.208***	-35.912***	-39.773***	0.356	0.079	-0.273	-8.378	-0.004	1.775
P9 × P10	0.482	0.019	3.139***	0.579	8.208	12.921**	13.810*	0.148	0.662	-0.106	12.006	0.024	8.834

* = significant at 0.05; ** = 0.01; *** = 0.001;

Appendix 0-4. General and specific combining ability effects for grain yield and other traits of ten maize inbreds evaluated under combined heat and drought stress conditions in Chókwè 2015.

Parent/cross	GY	NP	GWPE	GWPP	GT	AD	ASI	PH	EPO	PA	SLODG	BHC	EA
						Parents GCA effects estimates							
P1	-0.089	-0.583	-1.850	-0.650	0.069	-0.483	0.017	-6.573***	-0.001	0.196	-1.138	1.455	0.054
P2	-0.034	-0.125	-3.308	-0.900	-0.398***	0.683*	-0.025	-1.198	0.007	0.175	1.162	-2.245	0.013
P3	-0.405***	-1.625	-3.933	-7.192**	-0.127	0.017	0.183	3.635	-0.003	0.175	1.383	-0.595	0.075
P4	0.143	2.625**	3.942	2.100	-0.627***	0.475	-0.025	0.868	0.043***	-0.075	0.433	3.005*	-0.258**
P5	-0.045	-2.500*	-3.683	-0.400	-0.106	-0.108	0.100	-8.957***	-0.024***	0.008	-2.034	8.072***	0.304***
P6	0.066	-0.292	-0.975	0.225	0.040	1.350***	-0.108	14.293***	-0.010	-0.304**	0.103	-1.849	0.117
P7	0.316***	1.792	6.817*	9.142***	0.269**	-0.317	0.058	2.577	0.016**	-0.200	-1.930	-1.62	-0.238**
P8	-0.101	2.083*	-6.392*	-6.608*	0.382***	0.475	0.225	-2.632	-0.007	0.196	1.153	-2.495	0.138
P9	0.083	0.375	4.233	0.725	0.603***	-0.150	0.225	8.302***	0.005	-0.117	3.603**	0.222	-0.071
P10	0.065	-1.750	5.150	3.558	-0.106	-1.942	-0.051	-10.315***	-0.026***	-0.054	-2.734*	-3.949**	-0.133
						Crosses SCA effects estimates							
P1 × P2	0.255	3.560	-4.931	4.972	0.419	0.074	0.407	-5.619	-0.007	-0.197	2.017	-2.128	-0.019
P1 × P3	0.104	-2.273	6.028	7.931	-0.185	-0.593	-0.051	5.614	-0.011	0.137	-0.204	-1.978	-0.248
P1 × P4	-0.185	0.144	-4.181	-4.694	-0.351	0.282	-0.843	-6.153	0.050**	0.053	1.679	8.789*	-0.081
P1 × P5	0.016	-2.398	12.111	2.139	-0.206	1.532	0.032	3.206	-0.016	-0.030	-3.154	-7.078*	-0.144
P1 × P6	-0.075	-1.273	-14.931	-4.819	0.315	-0.593	-0.468	1.089	-0.047**	0.282	1.108	2.843	-0.123
P1 × P7	0.324	3.310	21.278**	5.264	-0.914***	2.407**	0.699	11.272	0.031*	-0.822**	-3.325	-0.586	0.065
P1 × P8	-0.120	1.352	-1.847	-1.653	0.874***	-2.384**	0.366	-10.853	0.021	0.116	-2.608	-1.111	0.356
P1 × P9	0.097	-1.940	2.528	0.014	0.253	-0.426	0.116	1.614	-0.018	0.095	2.508	-0.294	-0.102
P1 × P10	-0.416	-0.481	-16.056*	-9.153	-0.206	-0.301	-0.009	-0.169	-0.004	0.366	1.979	1.543	0.294
P2 × P3	-0.163	-4.065	-9.847	-7.153	0.615**	0.907	0.532	-3.628	0.012	0.324	1.696	-3.511	0.127
P2 × P4	-0.062	-3.648	8.944	0.222	0.282	0.449	0.074	4.539	-0.011	0.074	-0.986	18.756***	-0.039
P2 × P5	-0.112	-0.856	0.236	-2.944	-0.239	-0.301	0.241	0.364	-0.010	0.157	-1.454	-10.011**	0.231
P2 × P6	-0.051	1.269	2.861	-3.903	-0.218	-0.426	0.074	-5.353	0.026	0.303	-3.725	-0.957	0.252
P2 × P7	-0.275	-1.815	-7.931	-3.486	-0.281	0.241	-0.259	4.564	0.000	-0.134	1.942	-3.553	-0.060

Parent/cross	GY	NP	GWPE	GWPP	GT	AD	ASI	PH	EPO	PA	SLODG	BHC	EA
Combined heat and drought (cont.)													
							Crosses SCA effects estimates						
P2 × P8	-0.162	4.227	-4.389	-6.403	-0.560**	-0.884	0.449	8.906	-0.013	-0.197	4.258	1.756	0.065
P2 × P9	0.059	2.269	-3.014	5.931	-0.114	-0.259	0.324	-2.228	0.007	-0.218	-1.658	0.072	0.106
P2 × P10	0.511*	-0.940	18.069*	12.764	0.094	0.199	-0.801	-1.5444	-0.005	-0.113	-2.088	-0.424	-0.664**
P3 × P4	0.106	-0.148	6.236	3.847	0.344	-0.218	0.032	1.439	-0.001	-0.259	-1.108	-6.194	0.065
P3 × P5	0.357	3.644	-1.806	3.014	-0.510*	-0.968	-0.801	3.331	0.017	-0.509	-1.342	12.406***	0.002
P3 × P6	-0.090	2.102	-1.181	-3.944	0.178	0.241	-0.801	14.347**	-0.018	0.137	-0.513	-4.174	0.023
P3 × P7	-0.268	2.019	-18.972*	-10.528	-0.052	-0.759	-0.468	3.197	-0.003	-0.134	2.621	2.164	0.211
P3 × P8	0.251	-0.606	5.903	10.889	0.003	0.116	0.074	-14.728**	0.003	-0.197	3.704	-2.661	-0.331
P3 × P9	-0.112	2.102	1.944	-6.111	-0.218	1.741*	-0.426	-1.994	0.000	0.449	-5.146	5.056	0.211
P3 × P10	-0.184	-2.773	11.694	2.056	-0.176	-0.466	-0.259	-7.578	0.001	0.053	0.292	-1.107	-0.060
P4 × P5	-0.392	0.060	-12.347	-7.944	-0.010	-0.093	0.407	-1.969	0.017	-0.093	0.508	4.239	0.002
P4 × P6	0.010	5.185	-11.056	-6.236	0.011	-0.218	-0.384	-2.019	0.036	0.220	-4.963	-5.707	0.356
P4 × P7	0.403	-2.898	15.153	9.847	-0.051	0.116	1.116	-8.569	-0.009	0.782*	1.138	-6.669	0.044
P4 × P8	0.167	-0.190	8.028	7.597	0.169	0.657	-0.051	7.839	-0.046**	-0.780*	-2.679	-4.261	-0.164
P4 × P9	0.067	-2.481	-2.264	2.597	-0.218	-1.384	-0.384	2.239	-0.012	0.032	6.504*	-6.078	0.044
P4 × P10	-0.114	3.977	-8.514	-5.236	-0.176	0.407	-0.009	2.656	-0.025	-0.030	-0.092	-2.874	-0.227
P5 × P6	-0.024	-5.356	3.236	11.931	-0.176	0.366	0.491	6.739	-0.006	-0.197	5.104	-4.340	-0.039
P5 × P7	0.035	-5.106	-2.556	8.014	0.928***	-1.968*	-0.509	-9.411	-0.015	0.866**	-2.129	14.031***	0.315
P5 × P8	-0.065	4.935	-1.014	-10.236	0.149	1.241	0.324	-2.869	0.011	-0.030	2.688	-2.828	-0.060
P5 × P9	0.016	1.644	2.361	-1.903	0.261	0.532	0.991	7.531	0.005	-0.051	-0.396	-3.611	-0.352
P5 × P10	0.169	3.435	-0.222	-2.069	-0.197	-0.343	-0.650	-6.919	-0.004	-0.113	0.175	-2.807	0.044
P6 × P7	0.456	6.019	16.403*	8.389	-0.218	0.574	-0.093	-6.261	-0.006	-0.488	1.667	0.051	-0.831***
P6 × P8	0.135	-1.940	5.278	5.806	-0.164	-0.216	-0.718	-1.986	0.010	-0.051	-2.150	6.226	-0.206
P6 × P9	-0.044	-3.231	3.986	0.472	-0.051	-0.593	1.074	-9.119	0.011	-0.238	6.033	1.310	0.002
P6 × P10	-0.318	-2.773	-4.597	-7.694	0.324	0.866	0.282	2.564	-0.005	0.032	-2.563	4.747	0.565*
P7 × P8	-0.219	-5.690	-9.847	-3.778	-0.226	0.116	0.157	7.597	-0.002	0.345	0.217	-1.436	0.148
P7 × P9	-0.570*	2.019	-14.139	-15.778	0.219	-0.593	1.032	-7.536	-0.005	-0.176	-2.100	-2.153	0.356

Parent/cross	GY	NP	GWPE	GWPP	GT	AD	ASI	PH	EPO	PA	SLODG	BHC	EA
Combined heat and drought (cont.)													
						Crosses SCA effects estimates							
P7 × P10	0.115	2.144	0.611	2.056	0.594**	-0.134	-1.801	5.147	0.009	-0.238	-0.029	-1.849	-0.248
P8 × P9	0.131	0.060	3.736	2.639	-0.060	1.282	-0.176	4.872	-0.002	0.428	-5.750	3.622	-0.185
P8 × P10	-0.119	-2.148	-5.847	-4.861	-0.185	0.074	-0.301	1.222	0.019	0.366	2.321	0.693	0.377
P9 × P10	0.357	-0.440	4.861	12.139	-0.072	-0.301	0.366	4.622	0.013	-0.322	0.004	2.076	-0.081

* = significant at 0.05; ** = 0.01; *** = 0.001;

Appendices from chapter 5

Appendix 5-1. Grain yield and other agronomic traits of testcross hybrids evaluated under unstressed conditions at Chókwè in 2014/15 main season.

Entry	Testcross	Grain Yield		Anth	ASI	Plant	Ear	Ears/
		GW	Rank	Date		Height	Position	Plant
		t/ha	Rank	d	d	cm	0-1	#
1	TCL1/TESTER-A	5.72	35	52.5	1.7	257.8	0.58	1.08
2	TCL2/TESTER-A	5.42	58	48.6	4.8	253.8	0.52	1.09
3	TCL3/TESTER-A	5.58	41	54.5	2.8	245.8	0.57	1.06
4	TCL4/TESTER-A	6.76	8	56.2	1.5	275.6	0.56	1.07
5	TCL6/TESTER-A	6.35	19	52.4	3.0	248.4	0.56	1.05
6	TCL7/TESTER-A	4.58	96	52.4	5.8	245.4	0.52	1.10
7	TCL9/TESTER-A	6.09	27	51.2	2.4	233.2	0.56	1.06
8	TCL10/TESTER-A	6.06	29	52.0	2.5	240.9	0.52	1.07
9	TCL11/TESTER-A	4.91	81	50.8	3.3	250.6	0.52	1.11
10	TCL12/TESTER-A	5.89	32	53.0	4.0	267.8	0.56	1.08
11	TCL14/TESTER-A	5.50	48	53.4	1.5	268.1	0.57	1.07
12	TCL18/TESTER-A	6.38	17	52.6	2.3	269.1	0.57	1.02
13	TCL21/TESTER-A	5.30	65	53.2	2.8	250.3	0.61	1.07
14	TCL23/TESTER-A	5.26	68	55.4	3.6	267.5	0.58	1.07
15	TCL24/TESTER-A	4.43	106	52.5	3.2	248.6	0.52	1.11
16	TCL25/TESTER-A	5.36	59	54.6	0.7	244.5	0.54	1.07
17	TCL26/TESTER-A	6.77	7	54.5	1.5	262.3	0.61	0.99
18	TCL27/TESTER-A	5.25	69	54.3	1.7	266.4	0.58	1.06
19	TCL28/TESTER-A	8.13	1	55.4	1.9	258.6	0.54	1.02
20	TCL29/TESTER-A	5.71	36	54.9	2.3	267.7	0.61	1.05
21	TCL31/TESTER-A	6.63	11	53.6	3.6	241.2	0.59	1.05
22	TCL33/TESTER-A	5.59	40	54.8	2.0	272.5	0.61	1.06
23	TCL34/TESTER-A	4.78	88	54.3	2.1	234.4	0.52	1.12
24	TCL35/TESTER-A	6.16	23	54.3	2.3	260.6	0.63	1.04
25	TCL36/TESTER-A	7.01	5	56.1	1.2	256.2	0.56	1.05
26	TCL37/TESTER-A	3.85	120	57.0	2.4	233.8	0.54	1.15
27	TCL39/TESTER-A	6.65	10	53.8	1.8	266.9	0.61	1.29
28	TCL40/TESTER-A	5.45	53	54.8	2.4	249.6	0.56	1.20
29	TCL41/TESTER-A	2.32	128	59.1	2.1	244.1	0.50	0.94
30	TCL42/TESTER-A	4.78	89	56.3	2.9	222.6	0.53	1.06
31	TCL1/TESTER-B	4.11	111	51.0	2.3	240.8	0.58	1.10
32	TCL2/TESTER-B	4.53	100	48.6	4.0	228.6	0.56	1.09
33	TCL3/TESTER-B	3.11	126	54.0	1.9	225.1	0.61	1.02
34	TCL4/TESTER-B	3.89	119	53.8	2.1	266.5	0.58	1.04
35	TCL6/TESTER-B	5.00	78	52.1	2.9	239.5	0.64	1.11
36	TCL7/TESTER-B	6.54	14	53.1	2.9	248.2	0.59	1.04
37	TCL9/TESTER-B	4.75	90	52.7	1.6	230.5	0.60	1.06
38	TCL10/TESTER-B	4.49	103	51.8	3.2	231.4	0.59	1.10
39	TCL11/TESTER-B	2.75	127	53.2	2.4	224.8	0.60	1.11
40	TCL12/TESTER-B	4.86	83	53.3	3.5	246.1	0.59	1.12
41	TCL14/TESTER-B	5.70	37	51.6	2.5	239.9	0.61	1.13
42	TCL18/TESTER-B	4.94	80	55.1	0.9	262.0	0.61	1.06
43	TCL21/TESTER-B	5.28	66	50.0	2.4	224.7	0.53	1.08
44	TCL23/TESTER-B	7.67	3	53.4	2.7	232.7	0.64	1.08

Entry	Testcross	Grain Yield		Anth	ASI	Plant	Ear	Ears/
		GW	Rank	Date		Height	Position	Plant
		t/ha	Rank	d	d	cm	0-1	#
45	TCL24/TESTER-B	5.49	50	50.6	3.4	226.9	0.56	1.06
46	TCL25/TESTER-B	5.54	42	51.9	1.6	233.1	0.58	1.09
47	TCL26/TESTER-B	6.18	21	54.8	1.8	246.7	0.62	1.07
48	TCL27/TESTER-B	4.88	82	56.3	1.4	254.2	0.61	1.06
49	TCL28/TESTER-B	5.43	54	55.0	0.9	243.5	0.59	1.13
50	TCL29/TESTER-B	6.10	26	55.1	-0.5	255.4	0.58	1.20
51	TCL31/TESTER-B	5.53	44	53.1	2.7	220.9	0.65	1.08
52	TCL33/TESTER-B	5.46	51	55.1	2.0	270.7	0.66	1.06
53	TCL34/TESTER-B	5.01	76	51.0	1.7	221.9	0.59	1.12
54	TCL35/TESTER-B	5.17	74	55.2	2.0	229.8	0.62	1.15
55	TCL36/TESTER-B	6.59	13	56.0	0.7	241.9	0.57	1.08
56	TCL37/TESTER-B	6.13	24	53.0	2.3	228.3	0.59	1.03
57	TCL39/TESTER-B	6.46	15	56.1	1.6	268.5	0.62	1.08
58	TCL40/TESTER-B	6.18	22	54.2	2.5	244.0	0.62	1.13
59	TCL41/TESTER-B	4.03	114	55.8	-0.1	260.1	0.64	1.15
60	TCL42/TESTER-B	4.59	95	54.8	1.1	229.0	0.60	1.08
61	TCL1/TESTER-AB	5.30	63	50.2	1.8	249.8	0.58	1.06
62	TCL2/TESTER-AB	4.53	101	50.2	3.0	235.3	0.54	1.11
63	TCL3/TESTER-AB	4.96	79	52.8	1.3	250.3	0.57	1.07
64	TCL4/TESTER-AB	3.27	124	53.5	2.0	265.4	0.57	1.14
65	TCL6/TESTER-AB	5.35	61	50.7	2.9	230.8	0.62	1.13
66	TCL7/TESTER-AB	5.42	57	52.0	2.6	232.5	0.52	1.06
67	TCL9/TESTER-AB	5.95	31	50.2	2.5	224.2	0.60	1.08
68	TCL10/TESTER-AB	4.69	93	50.1	2.9	228.8	0.52	1.11
69	TCL11/TESTER-AB	7.57	4	51.7	6.0	239.5	0.60	1.27
70	TCL12/TESTER-AB	3.95	118	51.0	5.5	248.6	0.56	1.15
71	TCL14/TESTER-AB	5.86	33	53.3	1.4	250.5	0.60	1.06
72	TCL18/TESTER-AB	4.06	112	51.8	3.8	260.1	0.60	1.14
73	TCL21/TESTER-AB	5.46	52	53.8	0.9	229.0	0.55	1.07
74	TCL23/TESTER-AB	3.49	123	53.8	2.3	262.5	0.58	1.13
75	TCL24/TESTER-AB	4.84	85	51.6	1.9	241.3	0.52	1.12
76	TCL25/TESTER-AB	5.17	73	51.4	-0.5	232.1	0.51	1.12
77	TCL26/TESTER-AB	4.42	107	54.4	1.4	241.8	0.57	1.12
78	TCL27/TESTER-AB	4.66	94	53.4	1.1	248.0	0.60	1.05
79	TCL28/TESTER-AB	3.97	116	54.6	2.4	251.7	0.52	1.15
80	TCL29/TESTER-AB	5.24	70	52.2	1.1	247.1	0.61	1.07
81	TCL31/TESTER-AB	4.73	91	54.2	2.0	226.3	0.58	1.06
82	TCL33/TESTER-AB	5.30	64	57.1	1.8	274.2	0.60	1.07
83	TCL34/TESTER-AB	6.94	6	51.7	2.6	239.8	0.54	1.29
84	TCL35/TESTER-AB	4.85	84	54.4	1.3	244.9	0.59	1.09
85	TCL36/TESTER-AB	6.12	25	53.5	1.9	244.6	0.53	1.23
86	TCL37/TESTER-AB	6.19	20	52.6	3.3	246.5	0.56	1.21
87	TCL39/TESTER-AB	5.61	39	51.8	5.0	240.8	0.55	1.24
88	TCL40/TESTER-AB	6.59	12	54.6	0.2	251.3	0.58	1.02
89	TCL41/TESTER-AB	5.35	60	53.5	1.4	256.9	0.54	1.07
90	TCL42/TESTER-AB	3.76	121	53.6	2.3	241.6	0.58	1.19
91	TCL1/TESTER-X	4.83	86	54.2	2.3	254.1	0.63	1.07
92	TCL2/TESTER-X	3.72	122	51.5	2.3	232.0	0.54	1.17
93	TCL3/TESTER-X	5.53	43	52.2	3.8	247.1	0.56	1.07
94	TCL4/TESTER-X	3.16	125	55.9	1.9	270.9	0.62	1.15

Entry	Testcross	Grain Yield		Anth	ASI	Plant	Ear	Ears/
		GW	Rank	Date		Height	Position	Plant
		t/ha	Rank	d	d	cm	0-1	#
95	TCL6/TESTER-X	4.04	113	52.3	3.9	260.1	0.60	1.09
96	TCL7/TESTER-X	5.67	38	51.8	3.5	256.1	0.60	1.07
97	TCL9/TESTER-X	6.36	18	52.5	2.0	240.5	0.54	1.03
98	TCL10/TESTER-X	5.51	46	52.5	2.1	248.2	0.66	1.07
99	TCL11/TESTER-X	4.58	97	52.9	1.4	245.9	0.60	1.10
100	TCL12/TESTER-X	5.02	75	52.9	1.8	271.5	0.60	1.11
101	TCL14/TESTER-X	5.49	49	52.1	1.8	264.5	0.63	1.06
102	TCL18/TESTER-X	5.28	67	51.6	2.9	270.5	0.60	1.06
103	TCL21/TESTER-X	4.55	98	52.9	2.3	260.8	0.62	1.11
104	TCL23/TESTER-X	3.96	117	52.0	5.0	267.7	0.58	1.13
105	TCL24/TESTER-X	4.45	105	49.7	3.4	262.4	0.55	1.12
106	TCL25/TESTER-X	5.00	77	52.4	1.6	255.2	0.52	1.06
107	TCL26/TESTER-X	7.72	2	54.3	1.1	265.0	0.59	1.00
108	TCL27/TESTER-X	4.23	110	51.9	5.4	269.2	0.63	1.10
109	TCL28/TESTER-X	6.03	30	54.0	2.8	272.6	0.57	1.04
110	TCL29/TESTER-X	4.83	87	52.1	2.9	250.9	0.61	1.09
111	TCL31/TESTER-X	4.26	109	51.2	2.9	259.6	0.65	1.10
112	TCL33/TESTER-X	5.50	47	57.2	1.1	279.9	0.66	1.09
113	TCL34/TESTER-X	5.53	45	52.3	1.7	258.7	0.56	1.06
114	TCL35/TESTER-X	6.09	28	55.1	2.1	264.6	0.60	1.16
115	TCL36/TESTER-X	5.19	72	52.8	3.2	239.7	0.59	1.11
116	TCL37/TESTER-X	6.72	9	52.1	3.1	247.5	0.61	1.08
117	TCL39/TESTER-X	3.98	115	56.0	2.5	287.7	0.65	1.08
118	TCL40/TESTER-X	4.30	108	53.3	3.5	262.2	0.58	1.12
119	TCL41/TESTER-X	4.50	102	54.1	1.7	271.1	0.58	1.05
120	TCL42/TESTER-X	4.69	92	54.0	2.3	257.4	0.61	1.10
121	TESTER-B/TESTER-AB	4.46	104	56.1	1.8	257.2	0.61	1.42
122	TESTER-A/TESTER-AB	5.79	34	54.1	1.5	241.3	0.61	1.08
123	TESTER-A/TESTER-X	4.54	99	54.9	4.5	254.1	0.60	1.12
124	TESTER-AB/TESTER-B	5.33	62	54.6	1.2	241.5	0.60	1.08
125	TESTER-B/TESTER-X	5.42	55	54.3	4.4	258.1	0.58	1.08
126	TESTER-AB/TESTER-X	5.21	71	51.6	4.5	249.7	0.59	1.09
127	TESTER-A1/TESTER-A2	5.42	56	53.1	3.1	241.1	0.56	1.11
128	TESTER-B1/TESTER-B2	6.40	16	56.0	2.1	271.1	0.67	1.11
Mean		**5.25**	**65**	**53.3**	**2.4**	**249.7**	**0.58**	**1.10**
LSD		**2.15**	**37**	**2.5**	**2.4**	**17.4**	**0.05**	**0.10**
MSe		**1.21**		**1.7**	**1.5**	**94.1**	**0.00**	**0.00**
CV		**20.99**		**2.4**	**50.9**	**3.9**	**4.68**	**4.65**
p		**0.000**		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Min		**2.32**	**1**	**48.6**	**-0.5**	**220.9**	**0.50**	**0.94**
Max		**8.13**	**128**	**59.1**	**6.0**	**287.7**	**0.67**	**1.42**

Appendix 5-2. Grain yield and other agronomic traits of testcross hybrids evaluated under unstressed conditions at Chókwè in 2014/15 main season.

Entry	Testcross	Grain Yield		Anth	ASI	Plant	Ear	Ears/
		GW	Rank	Date		Height	Position	Plant
		t/ha	Rank	d	d	cm	0-1	#
1	TCL1/TESTER-A	2.44	42	56.5	9.4	259.9	0.64	1.09
2	TCL2/TESTER-A	2.44	44	56.7	9.3	245.1	0.55	1.05
3	TCL3/TESTER-A	2.43	46	59.6	8.5	244.2	0.59	1.03
4	TCL4/TESTER-A	2.56	31	59.1	5.0	273.2	0.56	1.04
5	TCL6/TESTER-A	1.80	101	58.0	7.4	250.1	0.58	1.07
6	TCL7/TESTER-A	2.84	8	59.6	6.7	245.5	0.53	1.09
7	TCL9/TESTER-A	1.84	100	56.9	6.5	237.0	0.55	1.03
8	TCL10/TESTER-A	2.70	21	59.3	7.0	247.1	0.58	1.09
9	TCL11/TESTER-A	2.37	54	55.5	9.6	253.4	0.51	1.11
10	TCL12/TESTER-A	2.58	29	57.5	8.9	259.3	0.55	1.05
11	TCL14/TESTER-A	2.52	36	60.0	9.0	261.8	0.55	1.01
12	TCL18/TESTER-A	2.23	68	57.0	5.8	261.9	0.55	1.04
13	TCL21/TESTER-A	1.48	117	59.0	4.1	262.0	0.56	0.99
14	TCL23/TESTER-A	2.46	41	60.6	7.6	257.5	0.58	1.03
15	TCL24/TESTER-A	2.05	85	60.4	5.4	250.1	0.48	1.02
16	TCL25/TESTER-A	2.76	16	61.5	5.5	241.6	0.54	1.01
17	TCL26/TESTER-A	2.41	47	60.6	4.9	264.1	0.60	1.04
18	TCL27/TESTER-A	2.02	89	59.5	5.5	239.9	0.60	1.08
19	TCL28/TESTER-A	2.92	6	58.1	5.9	234.0	0.59	1.10
20	TCL29/TESTER-A	2.14	76	58.4	5.6	252.9	0.61	1.03
21	TCL31/TESTER-A	2.74	18	57.1	7.1	252.1	0.62	1.07
22	TCL33/TESTER-A	3.12	2	59.9	6.6	276.3	0.59	1.11
23	TCL34/TESTER-A	2.64	25	56.5	6.9	240.5	0.54	1.05
24	TCL35/TESTER-A	2.80	11	59.4	5.4	245.1	0.66	1.07
25	TCL36/TESTER-A	2.80	12	54.5	6.0	259.4	0.55	1.02
26	TCL37/TESTER-A	1.14	125	61.3	4.0	231.9	0.57	0.89
27	TCL39/TESTER-A	3.01	4	59.4	5.6	265.3	0.62	1.20
28	TCL40/TESTER-A	2.64	26	61.0	3.1	246.4	0.60	1.08
29	TCL41/TESTER-A	0.75	128	58.9	5.4	248.1	0.54	0.69
30	TCL42/TESTER-A	1.67	110	58.6	5.5	234.2	0.56	1.08
31	TCL1/TESTER-B	2.07	81	57.1	6.4	239.6	0.68	1.06
32	TCL2/TESTER-B	1.98	95	60.5	6.9	225.3	0.51	1.05
33	TCL3/TESTER-B	2.21	71	61.9	4.5	229.7	0.59	1.07
34	TCL4/TESTER-B	1.75	104	56.4	5.5	266.2	0.61	1.08
35	TCL6/TESTER-B	2.09	79	59.7	6.9	237.8	0.62	1.03
36	TCL7/TESTER-B	2.67	23	57.4	8.6	245.7	0.63	1.03
37	TCL9/TESTER-B	2.24	66	57.5	5.7	230.7	0.61	1.04
38	TCL10/TESTER-B	2.00	92	60.0	6.1	244.5	0.55	1.10
39	TCL11/TESTER-B	1.17	124	58.0	8.0	228.9	0.58	0.99
40	TCL12/TESTER-B	2.35	56	59.6	6.4	245.9	0.64	1.05
41	TCL14/TESTER-B	2.32	58	62.0	5.9	234.3	0.62	1.02
42	TCL18/TESTER-B	2.53	34	57.0	5.5	262.5	0.61	1.01
43	TCL21/TESTER-B	1.62	111	57.5	7.0	230.0	0.54	1.13
44	TCL23/TESTER-B	1.25	122	56.1	7.0	237.3	0.63	0.96
45	TCL24/TESTER-B	2.63	27	56.4	5.6	247.6	0.57	1.06
46	TCL25/TESTER-B	2.72	19	60.0	7.6	235.6	0.57	1.07
47	TCL26/TESTER-B	2.44	43	61.1	7.0	264.7	0.60	1.12

Entry	Testcross	Grain Yield		Anth	ASI	Plant	Ear	Ears/
		GW	Rank	Date		Height	Position	Plant
		t/ha	Rank	d	d	cm	0-1	#
48	TCL27/TESTER-B	1.53	116	57.5	7.0	249.5	0.62	1.11
49	TCL28/TESTER-B	2.74	17	60.3	5.2	243.7	0.59	1.08
50	TCL29/TESTER-B	3.13	1	58.9	6.5	244.7	0.61	1.16
51	TCL31/TESTER-B	1.57	114	60.5	6.4	221.7	0.67	1.12
52	TCL33/TESTER-B	2.55	32	58.9	5.9	265.7	0.62	1.07
53	TCL34/TESTER-B	2.27	63	59.0	6.1	230.9	0.61	1.03
54	TCL35/TESTER-B	2.38	53	60.0	6.4	256.3	0.62	1.04
55	TCL36/TESTER-B	2.54	33	59.0	4.6	235.2	0.59	1.20
56	TCL37/TESTER-B	2.22	69	60.1	5.4	242.5	0.59	1.19
57	TCL39/TESTER-B	1.99	94	59.5	5.5	249.7	0.68	1.08
58	TCL40/TESTER-B	1.69	109	58.4	7.5	240.8	0.59	1.12
59	TCL41/TESTER-B	2.46	40	60.0	6.1	265.1	0.59	1.02
60	TCL42/TESTER-B	2.03	87	59.0	5.6	233.7	0.59	1.10
61	TCL1/TESTER-AB	2.14	77	56.5	8.0	249.9	0.59	1.09
62	TCL2/TESTER-AB	2.53	35	58.0	6.4	232.6	0.52	1.12
63	TCL3/TESTER-AB	2.40	48	59.0	7.4	251.7	0.57	1.07
64	TCL4/TESTER-AB	1.43	120	57.0	7.6	256.5	0.58	0.99
65	TCL6/TESTER-AB	1.93	97	53.6	7.5	231.9	0.62	1.06
66	TCL7/TESTER-AB	2.91	7	59.8	6.1	225.4	0.52	1.10
67	TCL9/TESTER-AB	1.78	102	60.1	6.0	232.0	0.59	1.09
68	TCL10/TESTER-AB	2.40	50	56.0	7.0	236.6	0.52	1.07
69	TCL11/TESTER-AB	0.90	127	59.5	6.9	231.0	0.53	0.76
70	TCL12/TESTER-AB	1.74	105	57.9	5.6	253.8	0.57	1.10
71	TCL14/TESTER-AB	1.72	107	57.9	6.5	245.2	0.59	1.15
72	TCL18/TESTER-AB	2.63	28	59.1	5.5	268.3	0.57	1.05
73	TCL21/TESTER-AB	2.02	88	59.9	6.5	224.2	0.56	0.99
74	TCL23/TESTER-AB	2.16	74	60.0	7.4	250.1	0.60	1.04
75	TCL24/TESTER-AB	2.26	64	60.1	7.0	235.6	0.54	1.04
76	TCL25/TESTER-AB	2.33	57	58.5	4.9	232.1	0.53	1.02
77	TCL26/TESTER-AB	2.83	9	58.4	6.6	253.8	0.59	1.13
78	TCL27/TESTER-AB	2.40	49	59.5	7.1	252.4	0.60	1.05
79	TCL28/TESTER-AB	2.00	91	59.1	5.5	251.1	0.53	1.08
80	TCL29/TESTER-AB	2.51	37	58.0	7.2	248.8	0.63	1.03
81	TCL31/TESTER-AB	1.70	108	55.9	6.5	223.2	0.57	1.12
82	TCL33/TESTER-AB	2.32	59	60.0	5.5	276.2	0.62	1.04
83	TCL34/TESTER-AB	2.79	13	56.1	6.0	222.5	0.55	1.07
84	TCL35/TESTER-AB	2.72	20	57.0	5.1	243.8	0.60	1.11
85	TCL36/TESTER-AB	2.77	15	57.8	4.6	236.4	0.55	1.09
86	TCL37/TESTER-AB	2.20	72	57.0	6.5	250.7	0.57	1.04
87	TCL39/TESTER-AB	2.22	70	58.1	4.5	242.1	0.55	1.04
88	TCL40/TESTER-AB	2.56	30	59.5	4.4	253.2	0.57	1.01
89	TCL41/TESTER-AB	2.16	75	59.4	7.1	257.6	0.55	0.97
90	TCL42/TESTER-AB	2.69	22	59.1	6.0	234.1	0.60	1.06
91	TCL1/TESTER-X	2.08	80	57.1	7.1	261.2	0.58	1.00
92	TCL2/TESTER-X	2.23	67	58.8	4.9	267.8	0.52	1.00
93	TCL3/TESTER-X	1.53	115	58.1	6.5	256.6	0.56	1.08
94	TCL4/TESTER-X	1.22	123	59.6	6.0	265.7	0.60	0.89
95	TCL6/TESTER-X	2.06	83	60.0	4.8	255.5	0.61	1.08
96	TCL7/TESTER-X	2.40	51	60.6	3.5	270.5	0.54	1.10
97	TCL9/TESTER-X	2.28	62	60.1	4.9	253.2	0.55	1.02

Entry	Testcross	Grain Yield		Anth	ASI	Plant	Ear	Ears/
		GW	Rank	Date		Height	Position	Plant
		t/ha	Rank	d	d	cm	0-1	#
98	TCL10/TESTER-X	2.17	73	57.0	5.1	253.4	0.64	1.04
99	TCL11/TESTER-X	1.45	119	58.0	7.0	257.9	0.60	1.19
100	TCL12/TESTER-X	1.61	112	57.5	5.4	252.4	0.59	1.08
101	TCL14/TESTER-X	1.99	93	60.8	6.1	259.5	0.65	1.05
102	TCL18/TESTER-X	1.61	113	56.9	7.6	260.8	0.62	1.15
103	TCL21/TESTER-X	2.05	86	59.5	6.9	252.6	0.59	1.11
104	TCL23/TESTER-X	1.98	96	57.4	8.5	266.6	0.61	1.17
105	TCL24/TESTER-X	2.43	45	58.5	7.0	248.1	0.56	1.10
106	TCL25/TESTER-X	2.66	24	62.0	4.0	252.6	0.56	1.04
107	TCL26/TESTER-X	2.31	60	56.5	6.1	258.9	0.62	1.02
108	TCL27/TESTER-X	2.47	39	59.0	6.4	257.1	0.56	1.04
109	TCL28/TESTER-X	2.06	82	57.1	7.6	277.6	0.56	1.05
110	TCL29/TESTER-X	2.39	52	59.0	6.9	251.9	0.60	1.02
111	TCL31/TESTER-X	1.47	118	57.6	6.0	237.4	0.67	1.13
112	TCL33/TESTER-X	2.02	90	58.9	3.5	283.3	0.72	0.97
113	TCL34/TESTER-X	2.49	38	57.0	6.4	264.0	0.57	1.02
114	TCL35/TESTER-X	2.78	14	58.2	5.0	252.9	0.65	1.06
115	TCL36/TESTER-X	1.73	106	58.0	7.6	245.5	0.57	1.12
116	TCL37/TESTER-X	2.25	65	61.5	4.4	253.4	0.60	1.03
117	TCL39/TESTER-X	2.10	78	58.2	7.6	276.2	0.65	1.08
118	TCL40/TESTER-X	1.75	103	58.0	6.5	266.7	0.61	1.07
119	TCL41/TESTER-X	0.95	126	58.0	7.0	265.1	0.53	0.86
120	TCL42/TESTER-X	2.05	84	59.0	5.0	258.9	0.61	1.02
121	TESTER-B/TESTER-AB	2.37	55	60.0	7.0	258.9	0.62	1.34
122	TESTER-A/TESTER-AB	2.95	5	57.7	7.4	262.8	0.55	1.11
123	TESTER-A/TESTER-X	1.85	98	56.5	7.0	276.9	0.58	1.12
124	TESTER-AB/TESTER-B	3.09	3	60.1	5.4	255.1	0.65	1.06
125	TESTER-B/TESTER-X	1.33	121	57.6	7.6	234.6	0.63	0.96
126	TESTER-AB/TESTER-X	1.84	99	57.0	4.9	263.7	0.57	1.05
127	TESTER-A1/TESTER-A2	2.81	10	58.5	6.4	248.8	0.62	1.06
128	TESTER-B1/TESTER-B2	2.29	61	58.6	5.0	269.0	0.70	1.04
Mean		**2.20**	**65**	**58.6**	**6.3**	**249.9**	**0.59**	**1.06**
LSD	**0.74**		**37**	**1.9**	**2.2**	**16.5**	**0.05**	**0.11**
MSe		**0.15**		**0.9**	**1.3**	**106.9**	**0.00**	**0.00**
CV		**17.34**		**1.7**	**18.1**	**4.1**	**4.11**	**5.74**
p		**0.000**		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
p		***		***	***	***	***	***
Min		**0.75**	**1**	**53.6**	**3.1**	**221.7**	**0.48**	**0.69**
Max		**3.13**	**128**	**62.0**	**9.6**	**283.3**	**0.72**	**1.34**